Electroweak, Top and QCD Results from CDF at the TeVatron

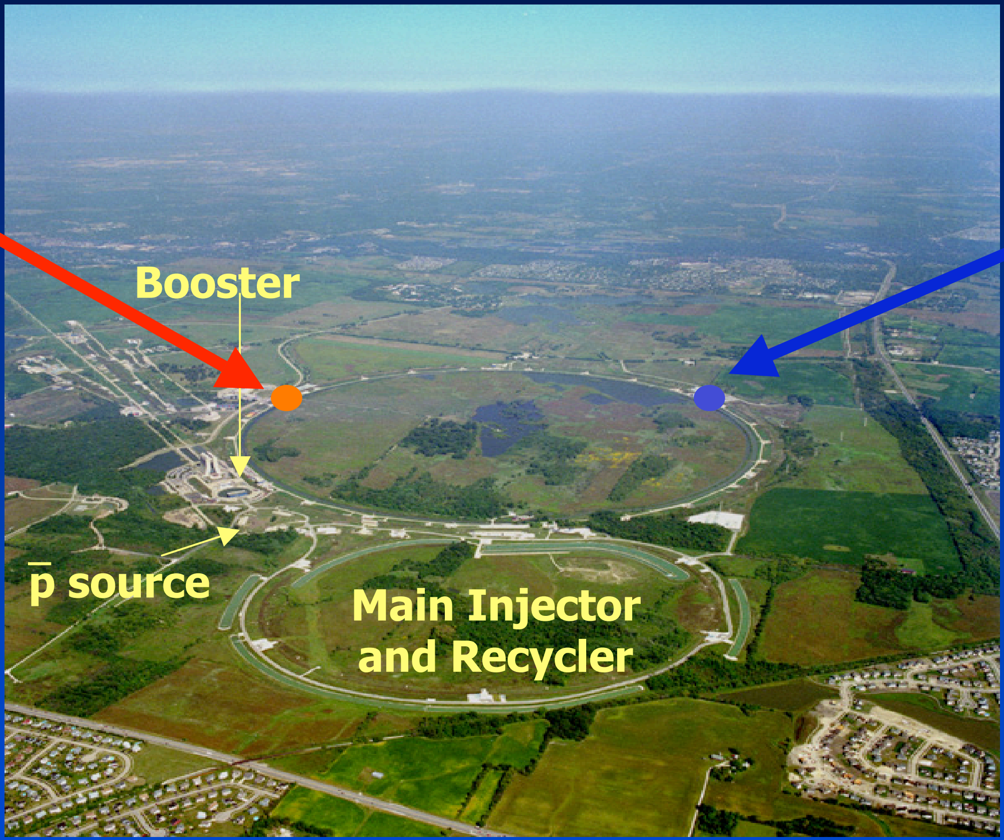
Beate Heinemann, University of Liverpool

- The TeVatron and the CDF Detector
- EWK: Di-Boson Production
- TOP: top-quark measurements
- QCD: double-pomeron exchange
- Conclusions

The TeVatron: Run 2

CDF

D0



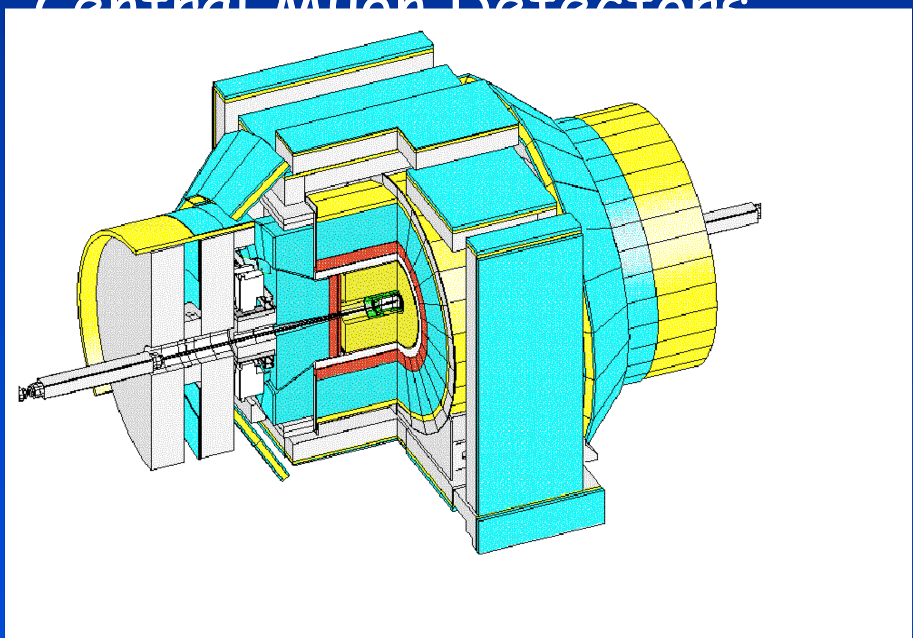
p-p̄ collisions at sqrt(s) ≈ 2.0 TeV

bunch crossing rate 396 ns

The CDF 2 Detector

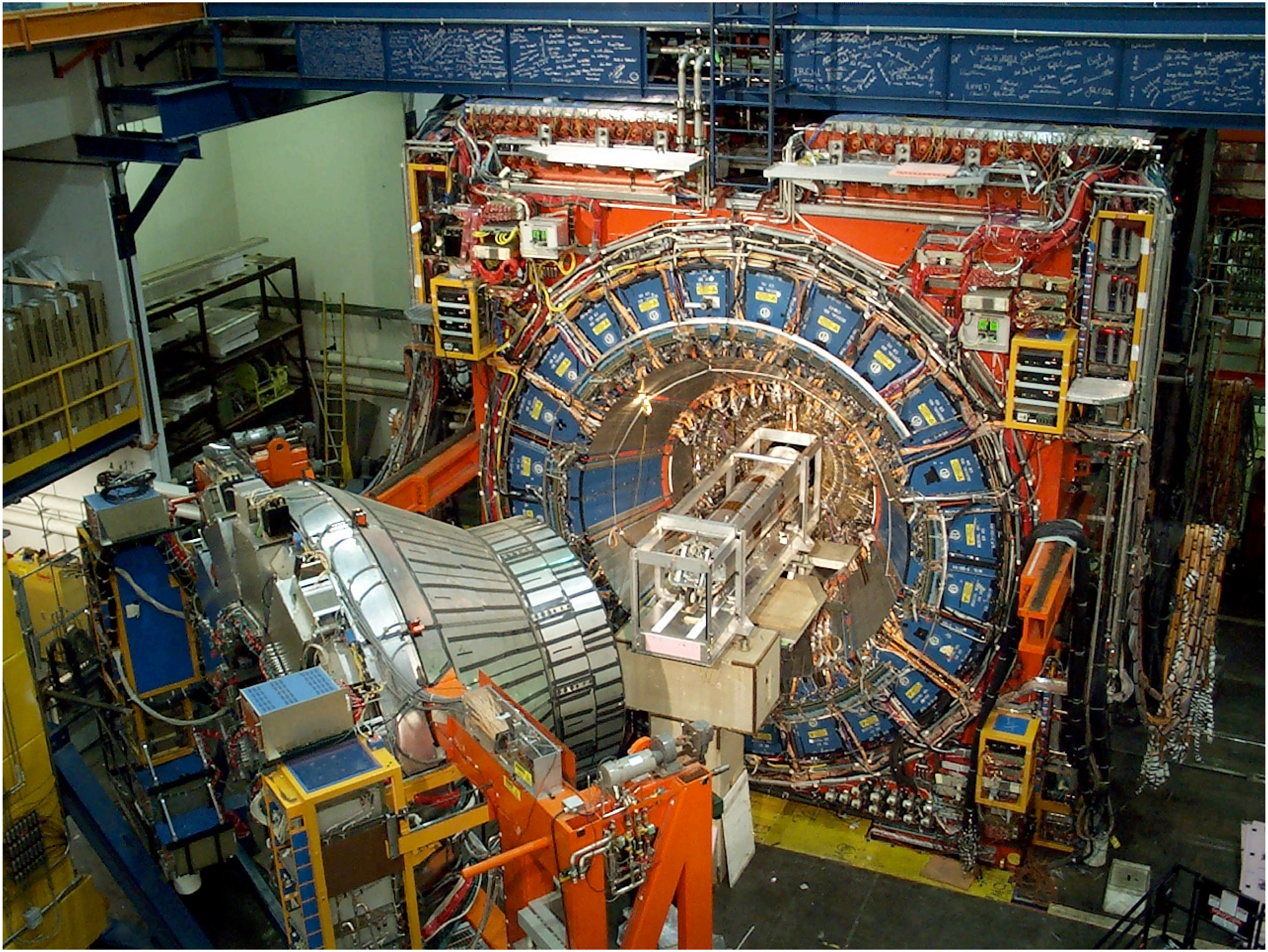
Retained from Run 1

- Solenoidal magnet (1.4 Tesla)
- Central Calorimeters
- Central Muon Detectors

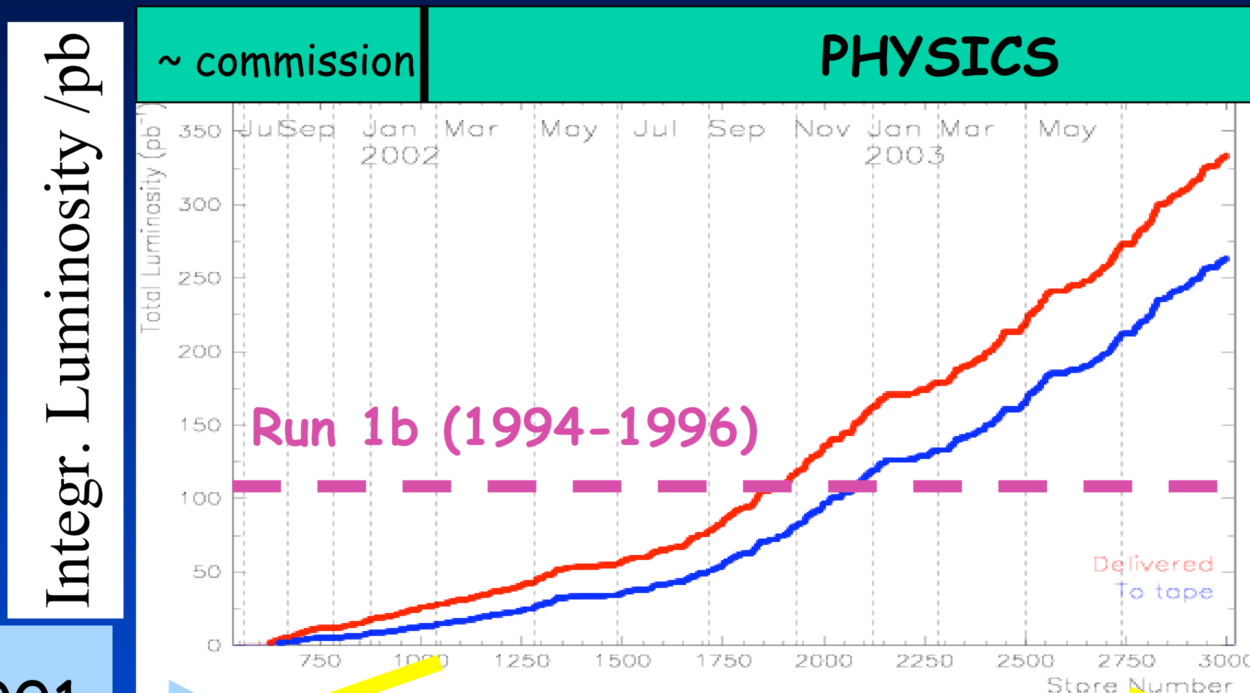


New for Run 2

- Tracking System
  - ✓ Silicon Vertex detector (SVX II)
  - ✓ Intermediate silicon layers (ISL)
  - ✓ Central Outer tracker (COT)
- Scintillating tile forward calorimeter
- Intermediate muon detectors
- Time-Of-Flight system
- Front-end electronics (132 ns)
- Trigger System (pipelined)
- DAQ system



CDF Run 2 Luminosity



~350 pb^{-1} delivered

~260 pb-1 recorded

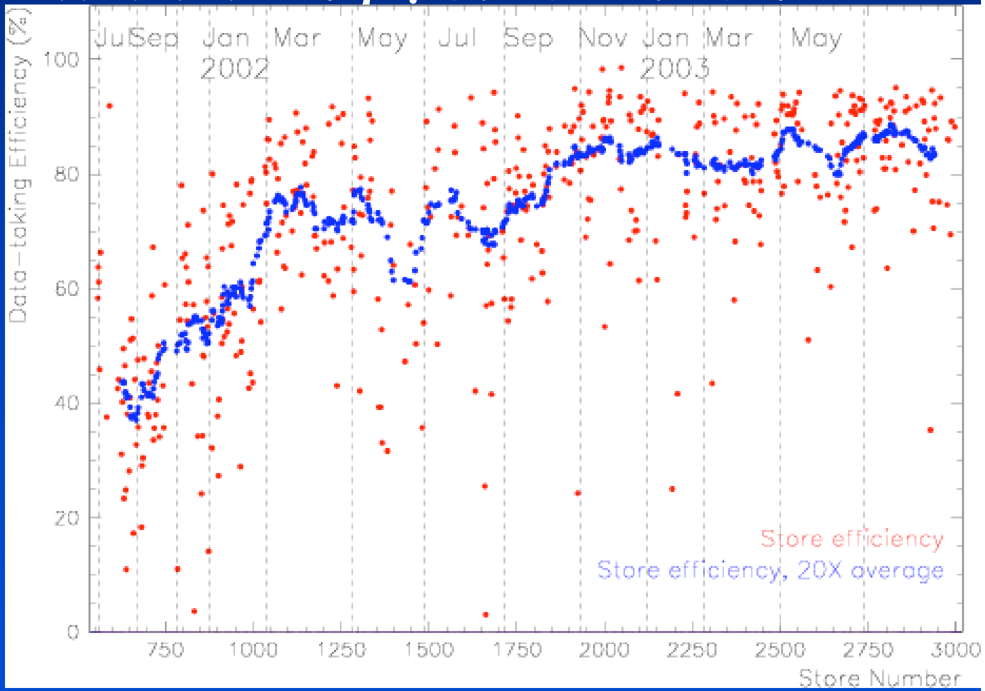
08/2001

09/2003

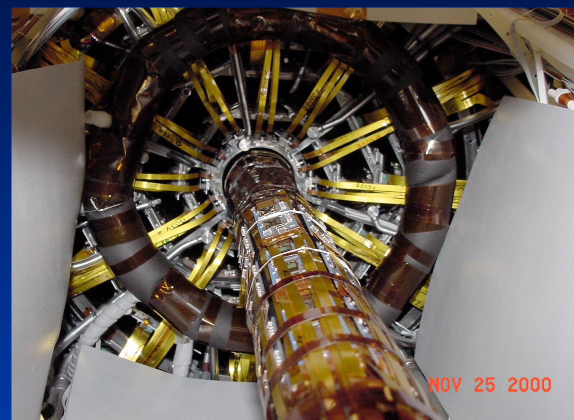
Physics Analyses use about 130 pb^{-1} recorded up to June 2003
(about 70 pb^{-1} good quality data on tape up to current shutdown)
Expect 2 /fb by 2006 and 4.4-8.6 /fb by 2009

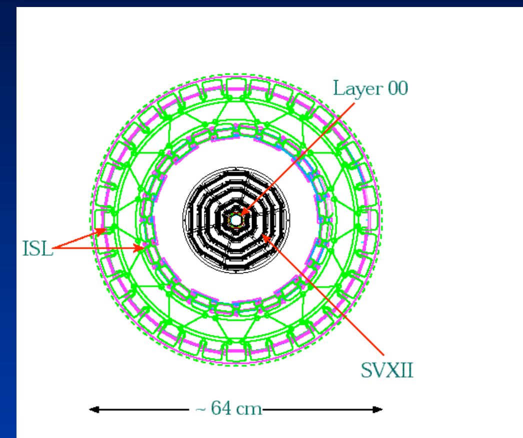
CDF: Data taking

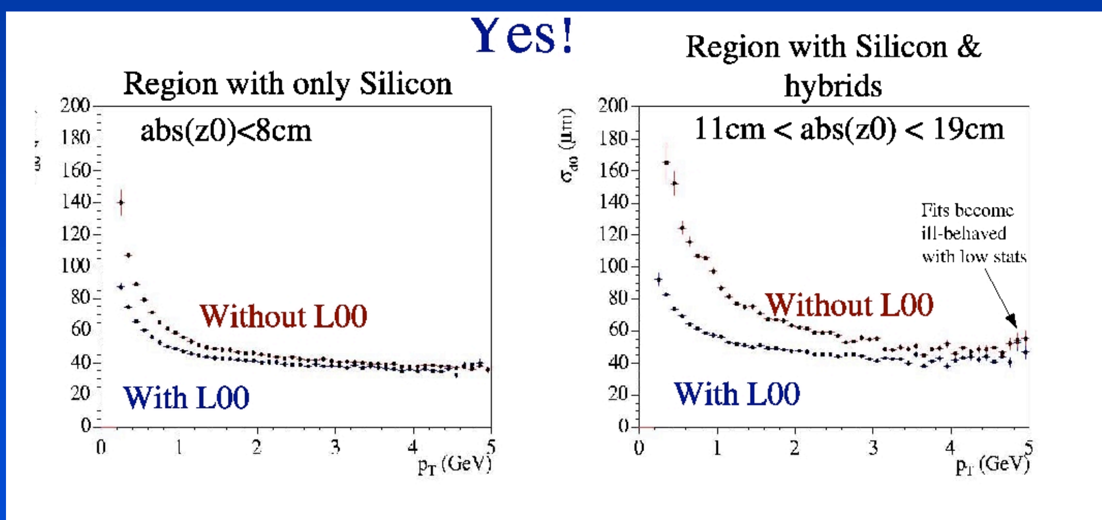
- All Sub-detectors fully operational
- Smooth and efficient data taking for over one year now!
- Efficiency (including Silicon) about 90%



Most Challenging part of CDF: Layer 00





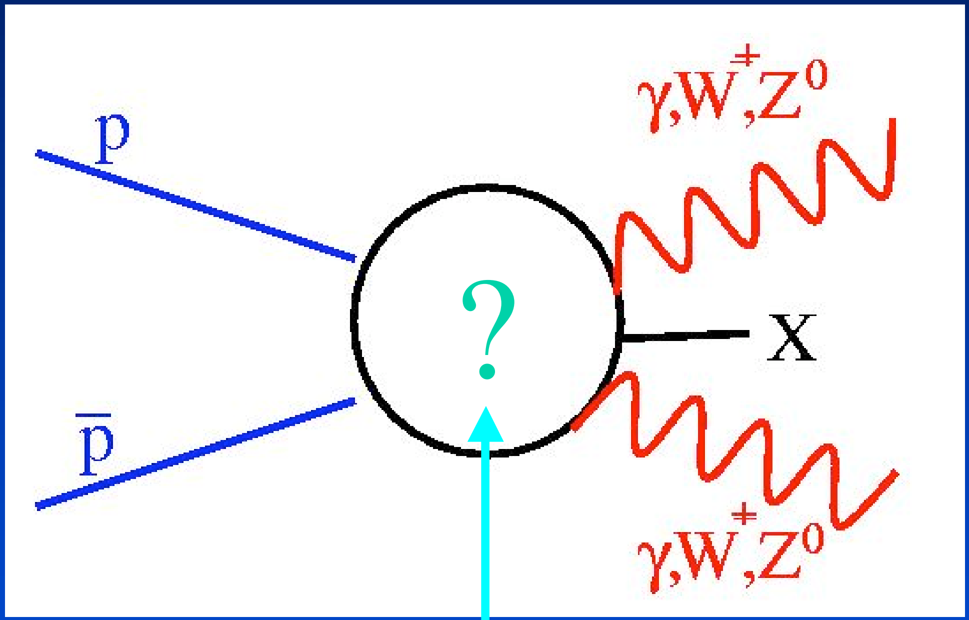


Impact parameter resolution greatly improved e.g. at 1 GeV subtracting 30 mm beamspot size:

33.5 mm_26.5 mm

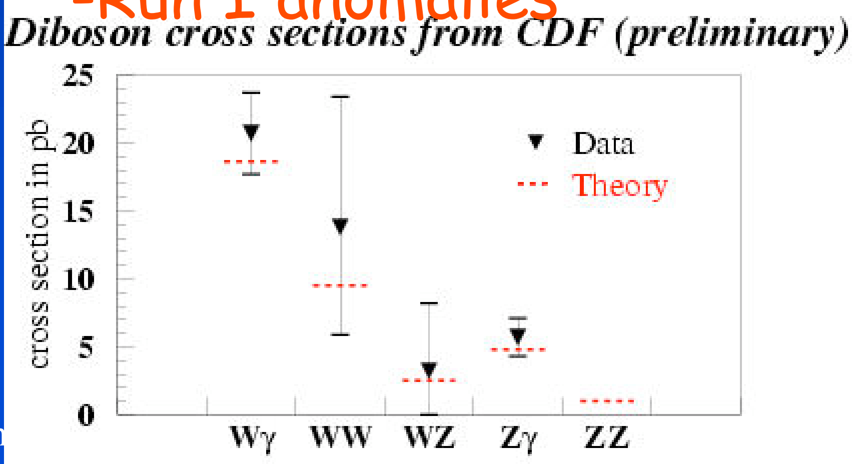
offline

Di-Boson Production: Why?



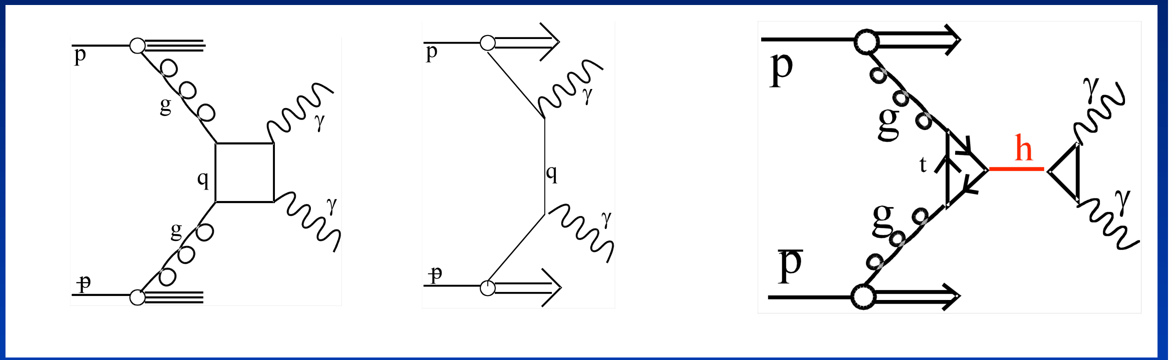
Something happens

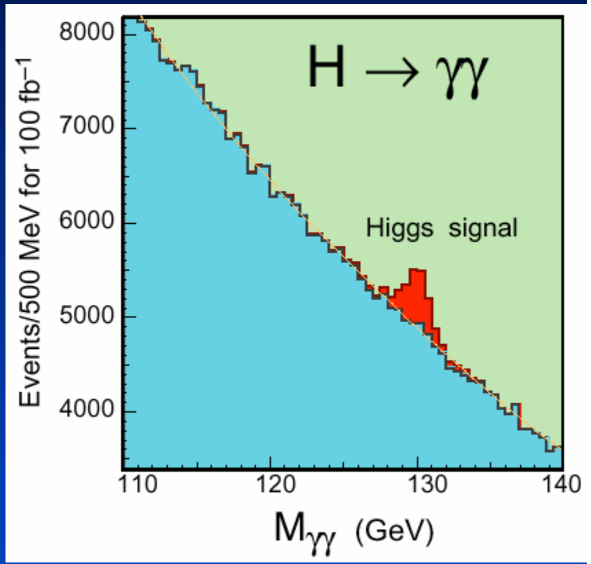
- -SM precision tests
- -SUSY
- -Large Extra Dimensions
- -Higgs
- -Run I anomalies



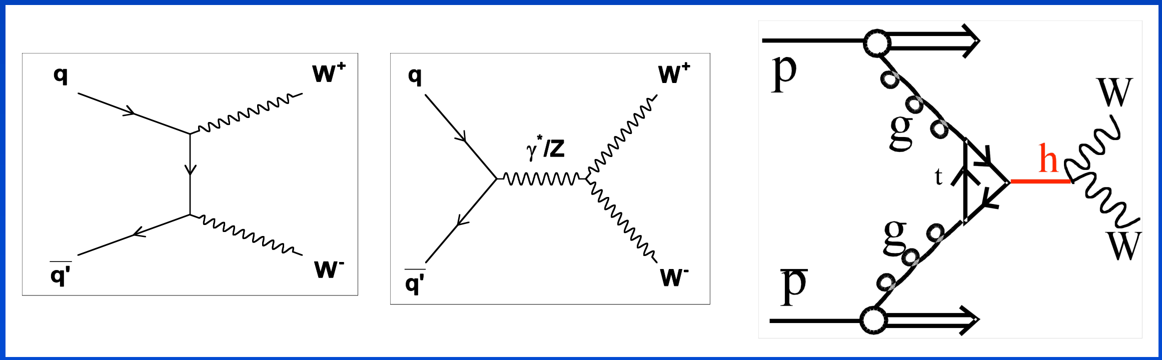
Di-Boson Production at the LHC

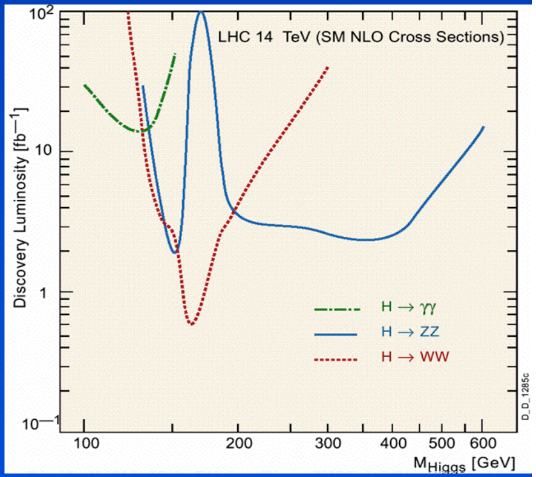
- Di-Photon Production:
  - discovery channel at LHC for mh<130 GeV





- WW and ZZ Production:
  - discovery channels at LHC for 500>mh>130 GeV





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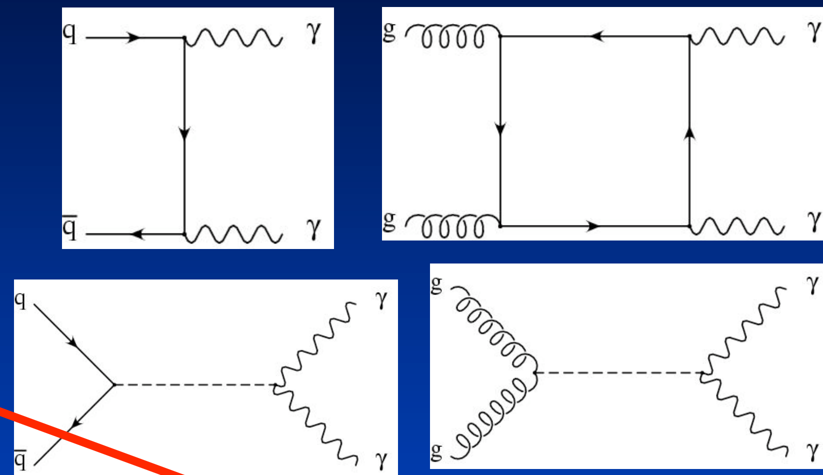
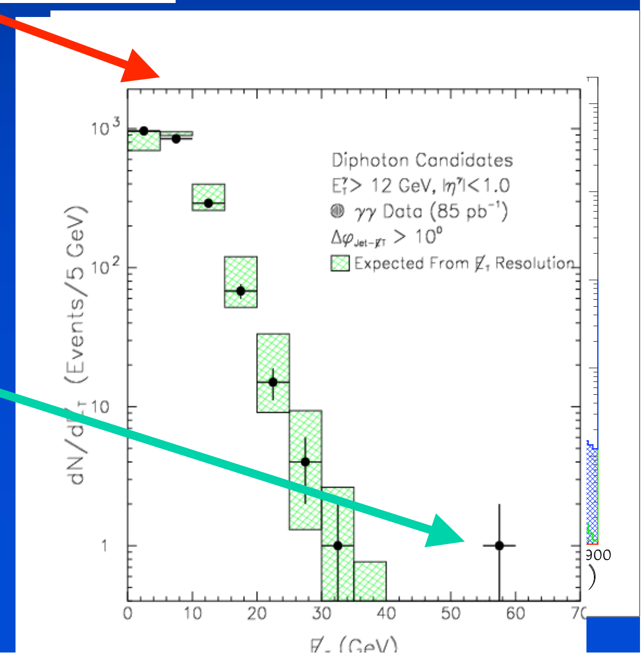
Di-Photon Production

- Irreducible BG to light higgs at LHC
- SM couplings small ($_{em}$)
- New Physics Scenarios:
  - Large Extra Dimensions:
    - Graviton exchange contributes
    - Present sensitivity about 900 GeV
  - Generic “bump” search
  - Extraodinary events with 2 photons and transverse momentum imbalance(?)





Di-Photon Mass Spectrum: Run 2

- **Search Selection:**

  2 photons with E_t>13 GeV, cosmic and beam-halo rejection cuts

- **Main backgrounds:**

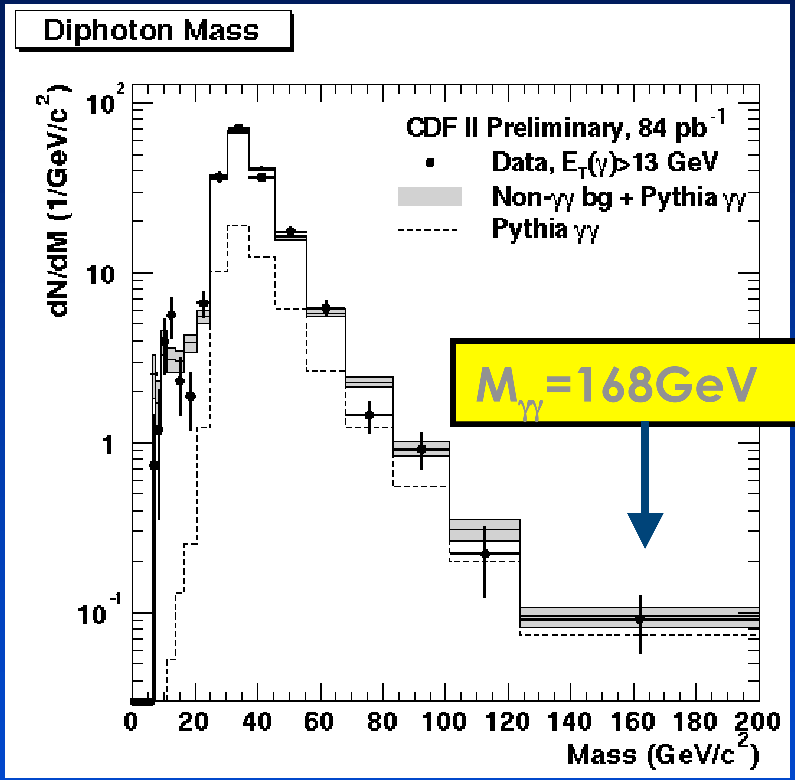
  fakes from photon-jet and jet-jet: determined from data!

- **Results:** 1365(95)events for E_t>13(25) GeV

For $M_{\gamma\gamma}$ > 150 GeV

Expected background: 4.5 ± 0.6

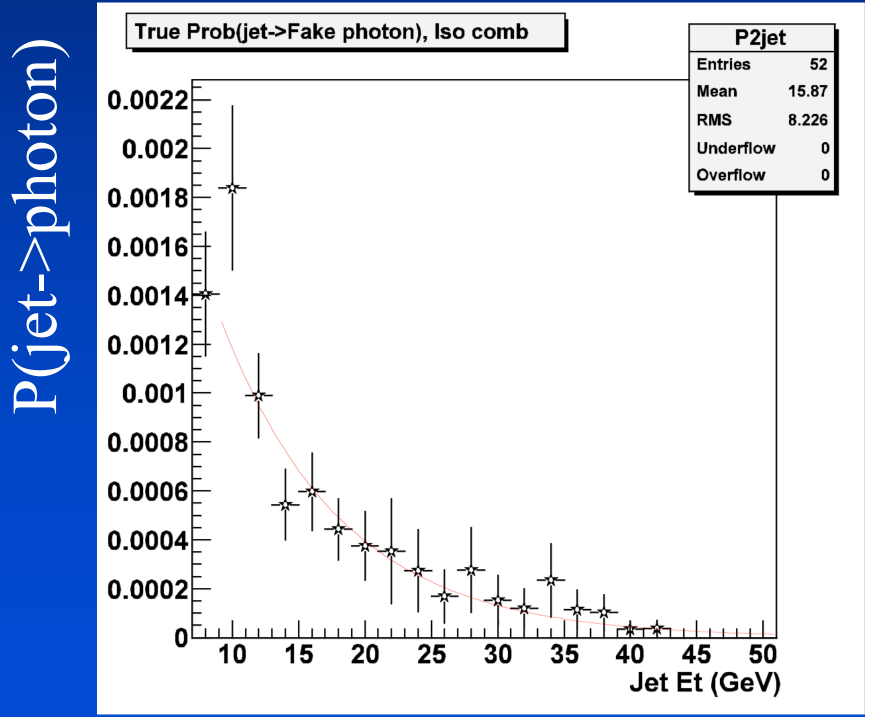
Observed: 5



Experimental Aspects: Photons

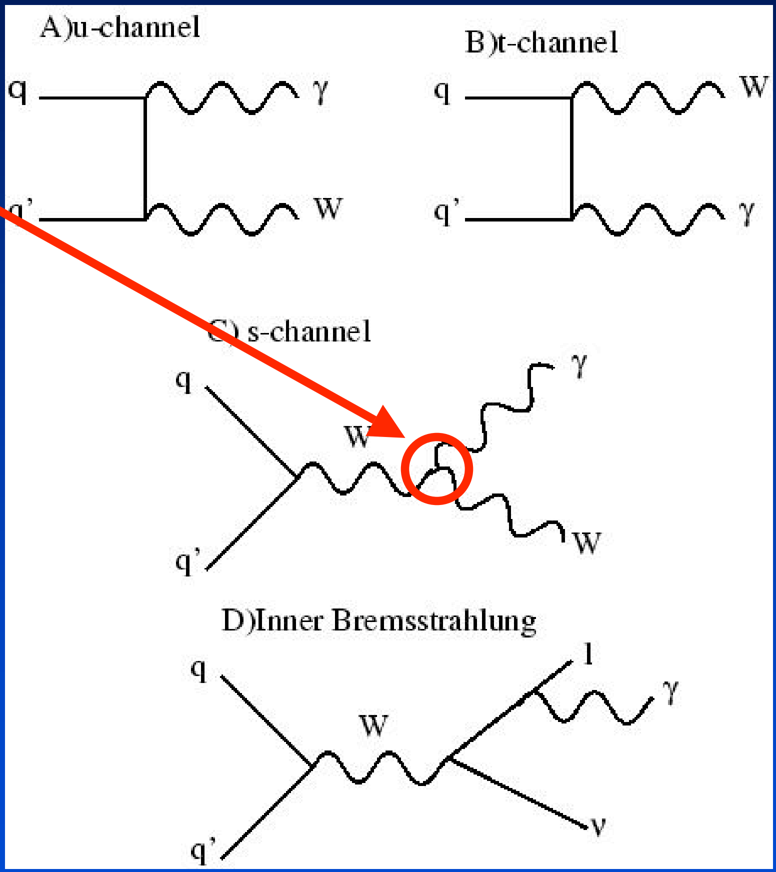
- Background: jet fragmenting into "single hard pi0":
  - Use high granularity strip and wire chambers in central calorimeter to separate pi0 from photon
  - New strip and wire chambers in forward calorimeter
- Traditionally difficult for MC generators:
  - high z fragmentation
  - Differences between data and MC of factors of 2-5 or so
- Important for LHC light Higgs scenario!

Probability of jet with π^0 carring more than 90% of energy: 0.1-0.01 %



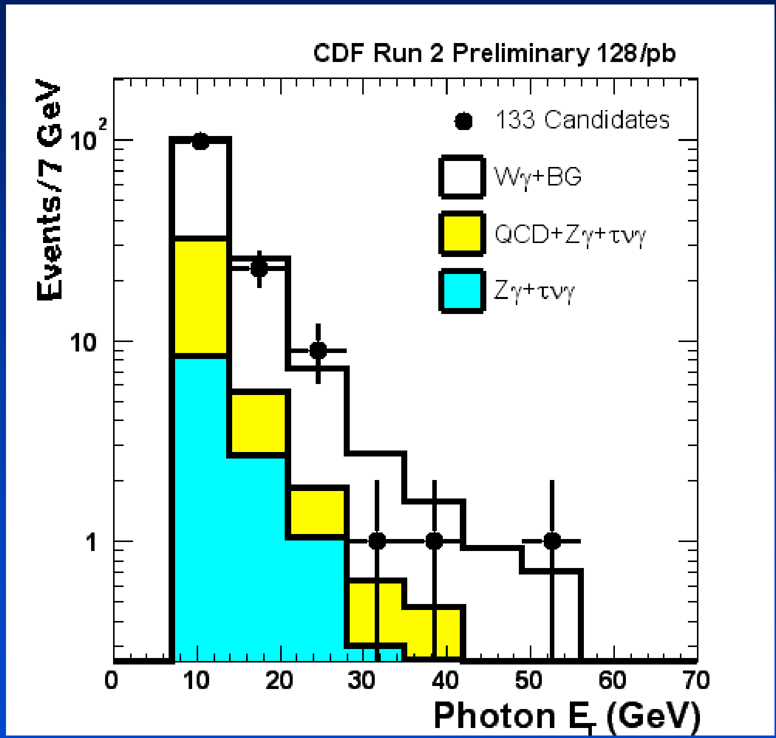
Di-Bosons: W/Z + Photon

- Sensitive to coupling of gauge bosons to each other: WW_ vertex
- Gauge structure of SU(2)xU(1) gives precise prediction
- Construct effective Lagrangian: introduce "anomalous couplings" _ and __
  - vanish in SM
  - May be sizeable if W not point-like
- Z+_ and _*+_ don't couple to another (diagram C non existent)



W+ Photon: first Run 2 Results

- Event selection
  - lepton Et and Met >25 (20) in electron (muon) channel
  - Photon Et>7 GeV, _R(l_)>0.7
- Largest uncertainty: BG from jets fragmenting into "single hard pi0" 30 - 10%

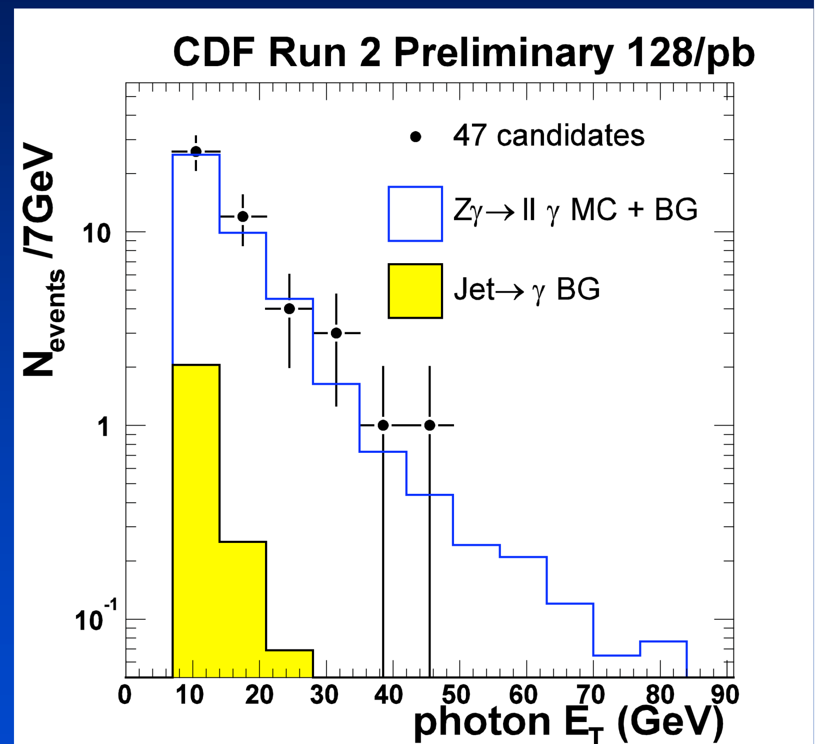


	Events
Signal MC	98.9±5.6
Jet->_	28.1±9.4
Other BG	13.7±0.7
SM exp.	140.7±11.0±6.8 (lumi)
Data	133

Z+ Photon: first Run 2 Results

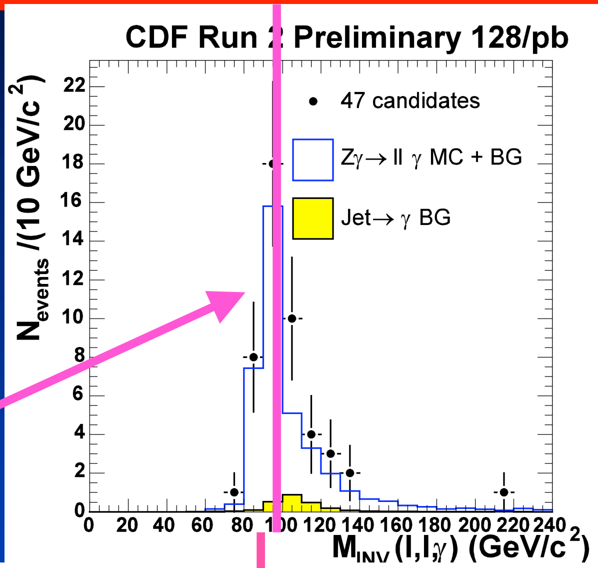
- Event selection
  - 2 leptons Et>25 (20) in electron (muon) channel
  - Photon Et>7 GeV , _R(l_)>0.7
- BG from jets fragmenting into "single hard pi0" only 5%

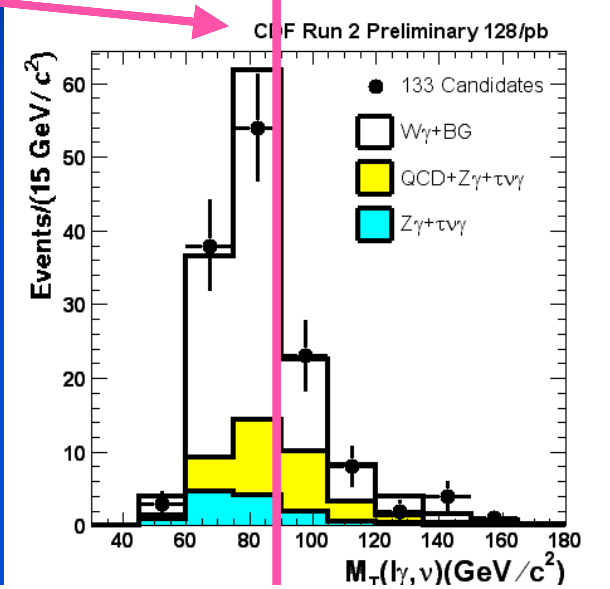
	Events
Signal MC	40.5±2.3
Jet->_	2.5±0.8
Other BG	0.2+0.3-0.2
SM exp.	43.2±2.3±2.4 (lumi)
Data	47



W/Z+ Photon: anomalous couplings

- Suppress final state radiation contribution:
  - Final state radiation: M(l_,_)<M_W , M(ll_)<M_Z GeV
  - S-, T- and U-channel: M(l_,_)>M_W , M(ll_)>M_Z GeV
- Experimentally:
  - Cut at M(l_,_)>90 GeV, M(ll_)>100 GeV
- Data in good agreement with SM prediction:
  - Anomalous coupling analysis not yet done
  - Will modify Et spectrum at high M(l_,_)>90 GeV / M(ll_)>100 GeV

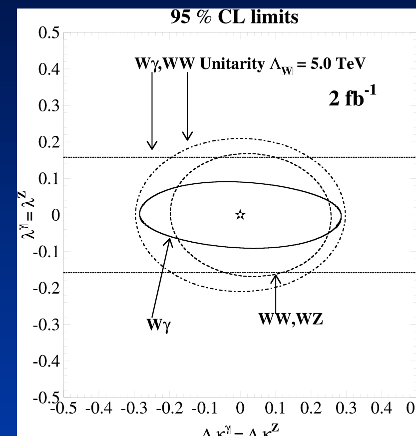


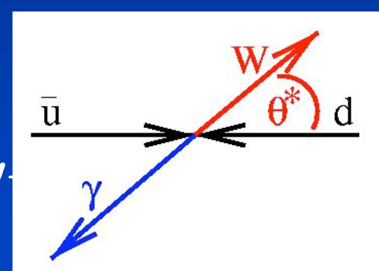


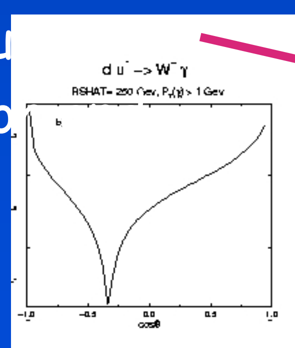
W/Z + Photon: Future

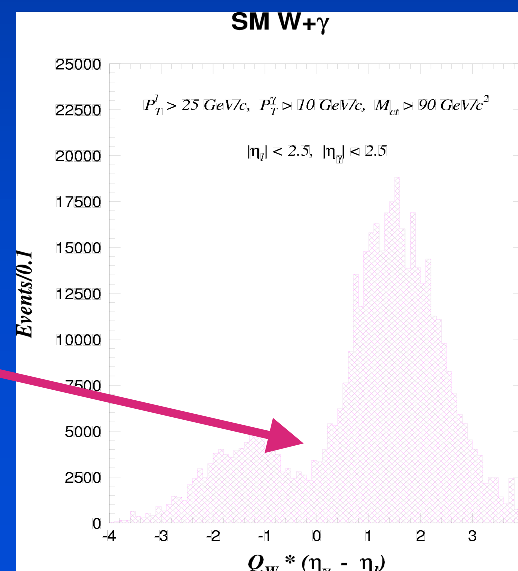
- Limits on __ and _:
  - Test SM at level of about 10(30)% in Run II
  - LEP 2 precision now: 2-3%
- "Radiation Zero" unique to TeVatron:
  - At LO suppressed e.g. for W
    cos_*=-(1+2Q$_i$)=-1/3
  - Observable in angu
    separation of lepto
    photon: __-__lepton

CDF II









W + Photon as Search

Run I: $\not{E}_t$>25 GeV, lepton Et>25 GeV, photon Et>25 GeV

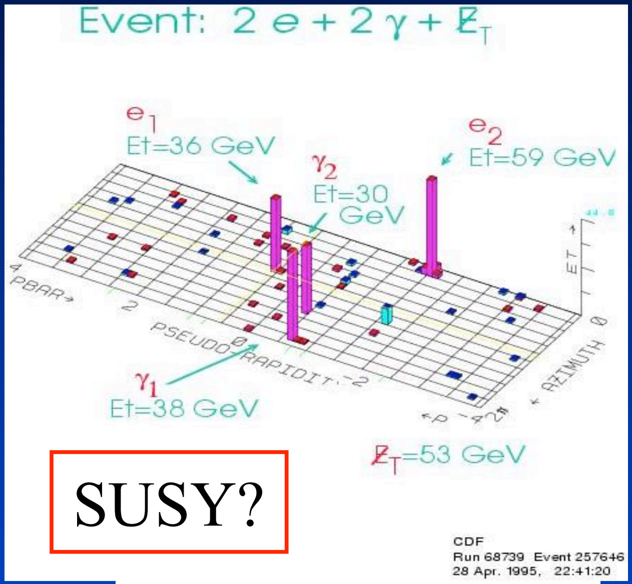
lepton	Data	SM exp
muon	11	4.2
electron	5	3.4
both	16	7.6

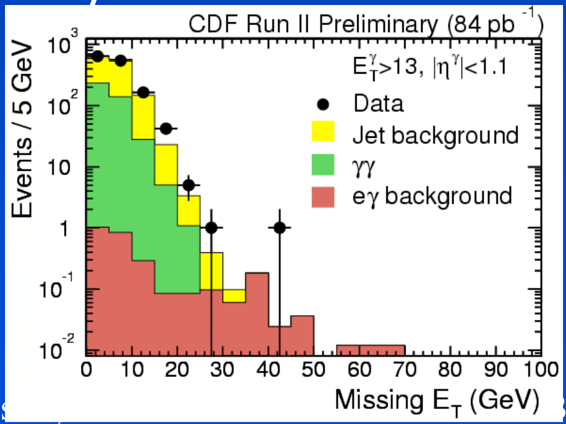
Phys. Rev. Lett. 89, 041802 (2002)

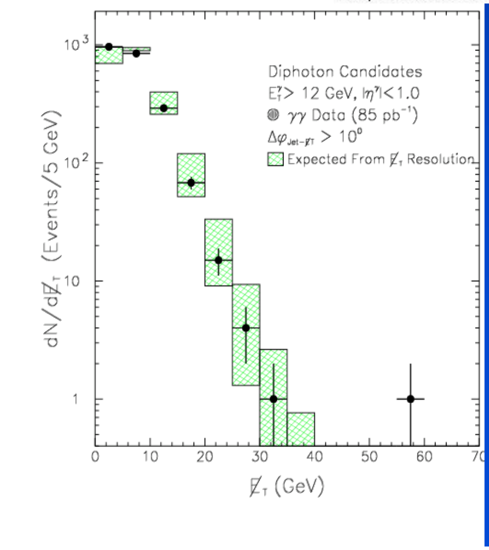
- Run 2: use W+_ analysis cuts and photon Et>25 GeV
  - SM exp: 9.6±0.4(stat.)±0.7(syst.)±0.5(lumi)
  - Data: 7
- Run 1 excess not confirmed in Run 2

W/Z+gamma+X: more exclusive channels

- Run I:
  - found 1 event with 2 photons, 2 electrons and large imbalance in transverse momentum
  - SM expectation 10^{-6} (!!!)
- Run II:
  - Any new such event would be







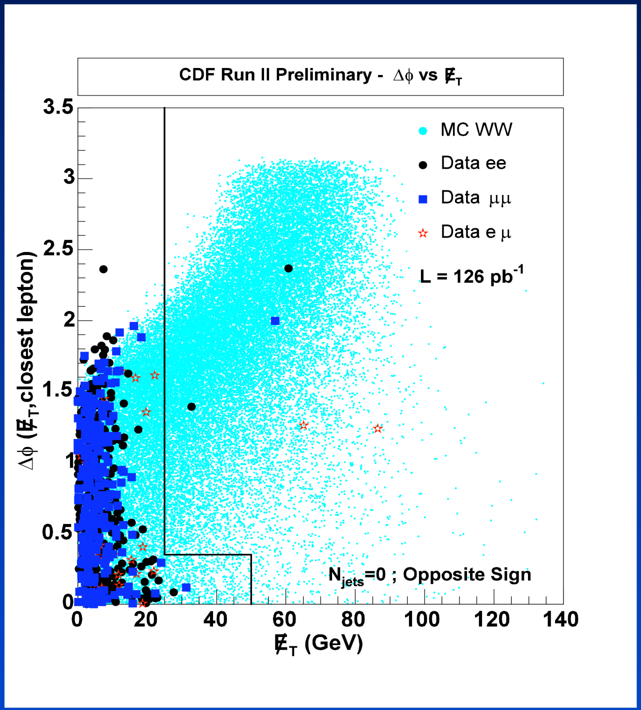
WW-Production in Run 2

- both W's decay leptonically
- Large backgrounds from

  tt->WWbb-> ll+bb+Et

- Suppressed by demanding no jets with Et>10 GeV
  - Large theoretical uncertainties (LO MC)

WW	6.9±1.5
Total SM	9.2±1.6
Run 2 data	5



Cross section:

5.1 +5.4-3.6±1.3 (sys)±0.3(lumi) pb

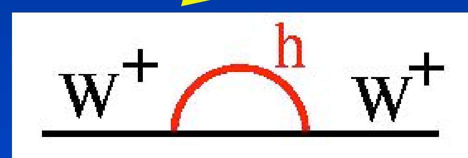
13.25 ±0.25 pb (J.M.Campbell, R.K.Ellis hep-ph/9905386)

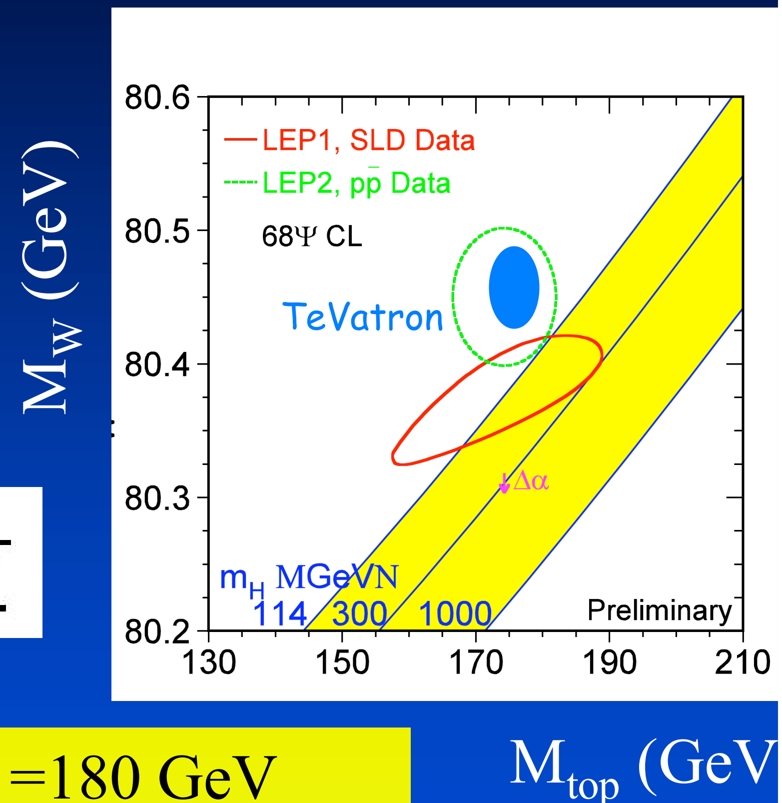
Motivation – Top Quark Mass

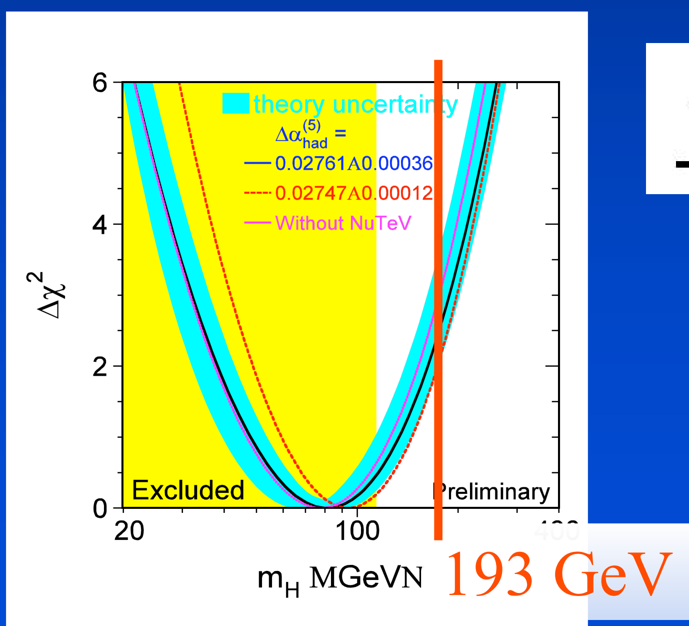
- Top Mass is a key electroweak parameter
- It has a LARGE mass that is close to the scale of electroweak symmetry breaking
  - Is top actively involved in EW symmetry breaking?
- Precise measurements of M_{top} and M_W constrain the Higgs mass in the Standard Model

Top Mass related to Higgs Boson Mass in SM

- Precision measurements of
  - M_W =80.450 +- 0.034 GeV/c^2
  - M_{top}=174.3 +- 5.1 GeV/c^2
- Prediction of higgs boson mass within SM due to loop



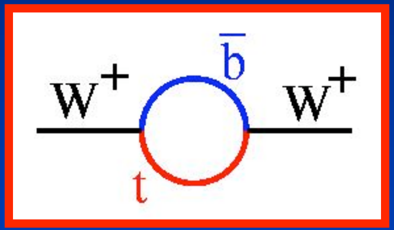




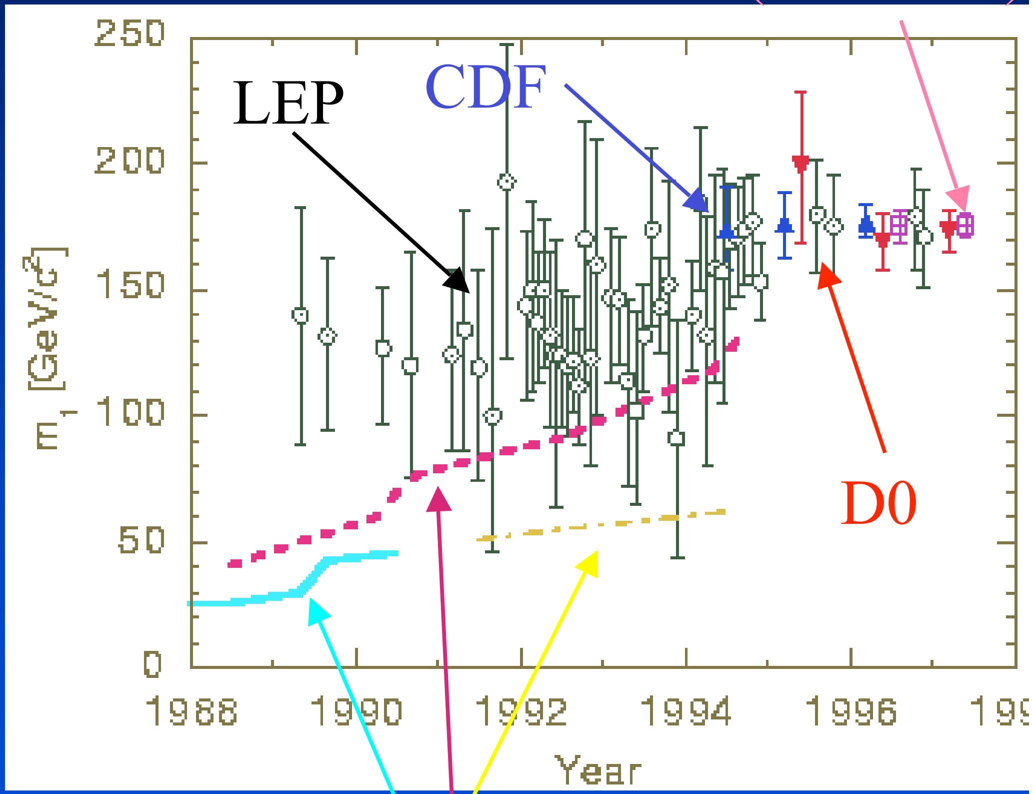
e.g. M_{top} =180 GeV shifts minimum to m_h=128 GeV!

Top Quark Historically

- 1989: Indirect constraints on top from precision measurements at LEP

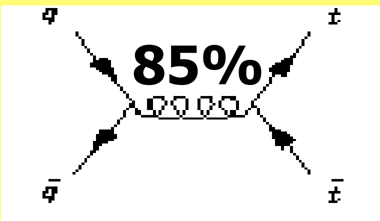


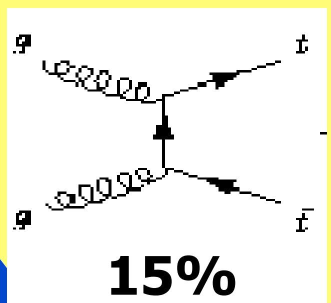
- 1995: Observation of Top-quark at the TeVatron
- Excellent agreement between indirect and direct measurements

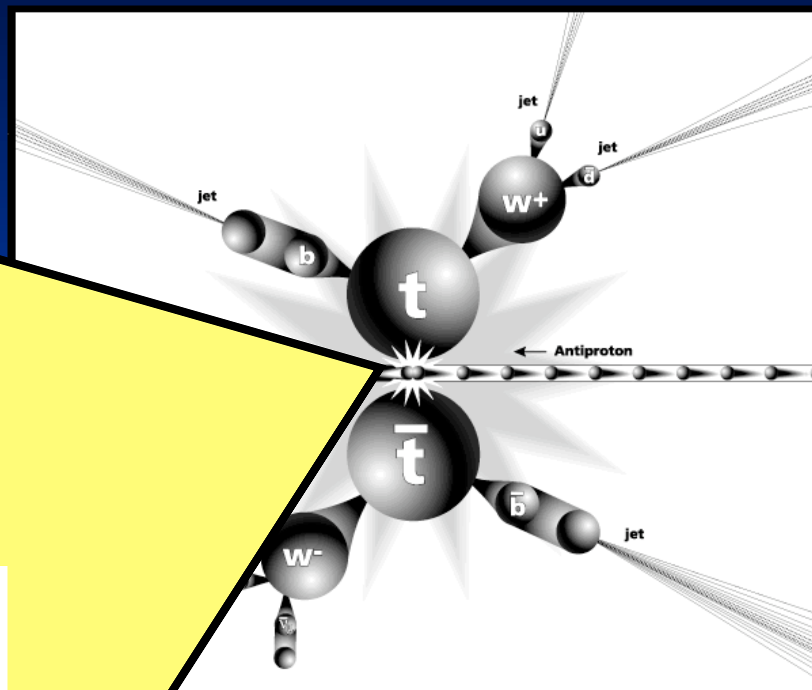


Top Quarks Production and Decay

Pair production







B(t_Wb) = 100%

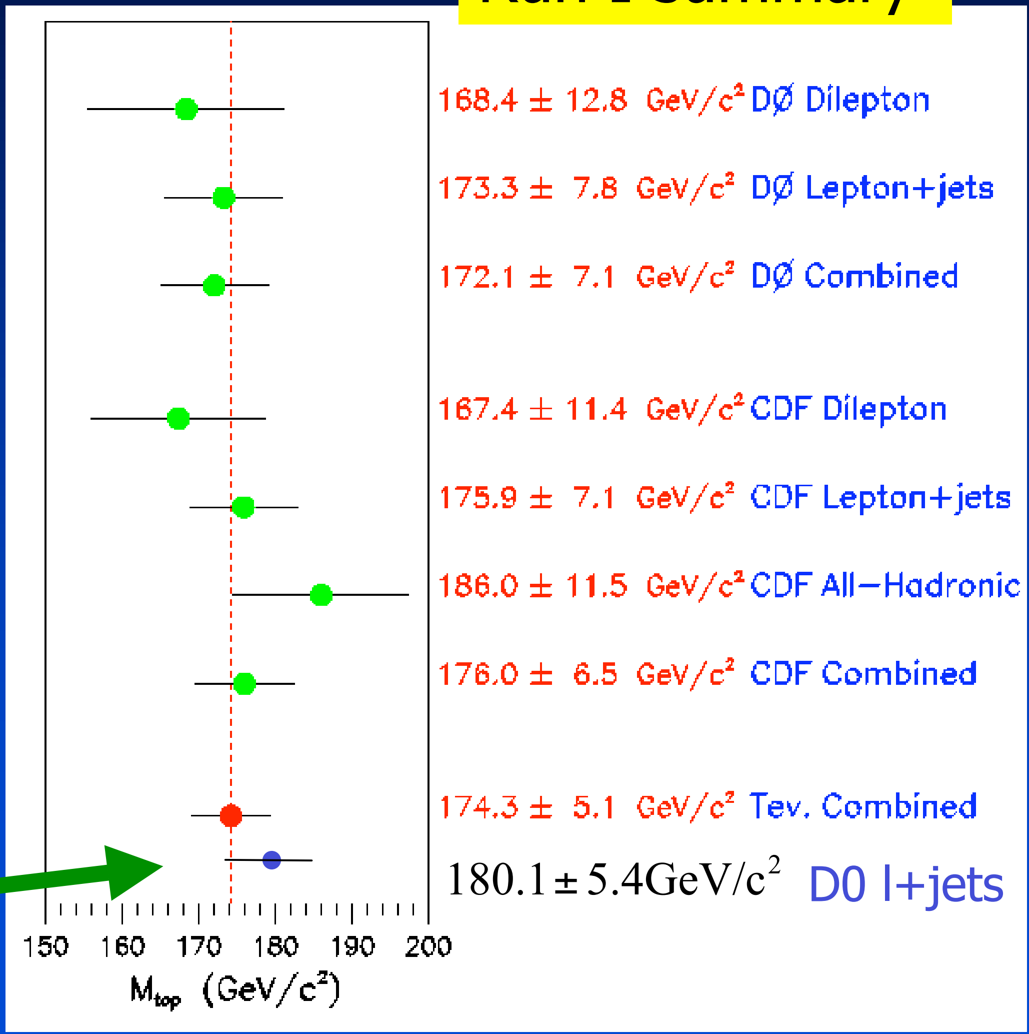
W decay modes used to classify the final states

•Dilepton (e,μ)	BR=5%
•Lepton (e,μ) +jets	BR=30%
•All jets	BR=44%
• τ_{had}+X	BR=21%

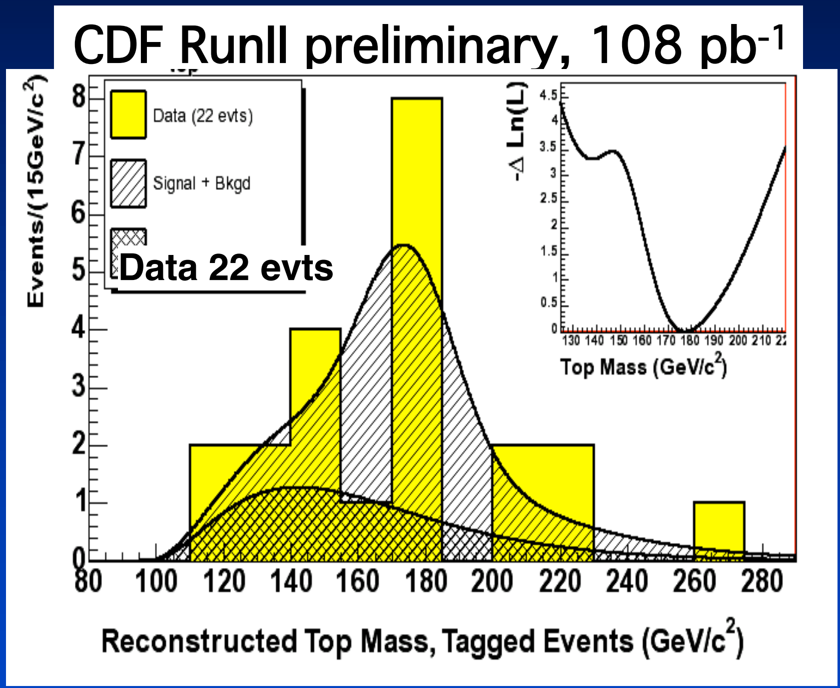
Top Mass Measurement

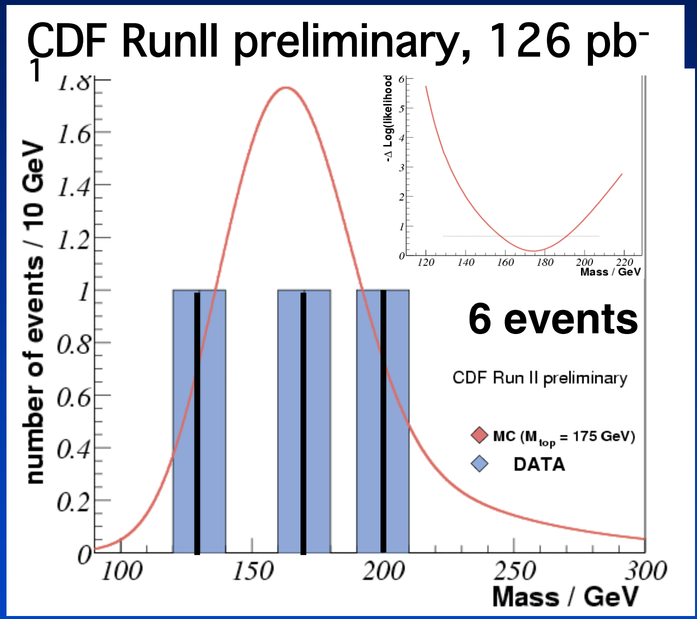
- Template method:
  - Kinematic fit under the tt hypotesis: use best χ^2 combination
  - Likelihood fit of mass to MC templates
- Dynamical method:
  - Event probability of being signal or background as a function of m(t)
  - Better use of event information → increase statistical power
  - New D0 Run I result:

Run I summary



First look at top mass in Run II





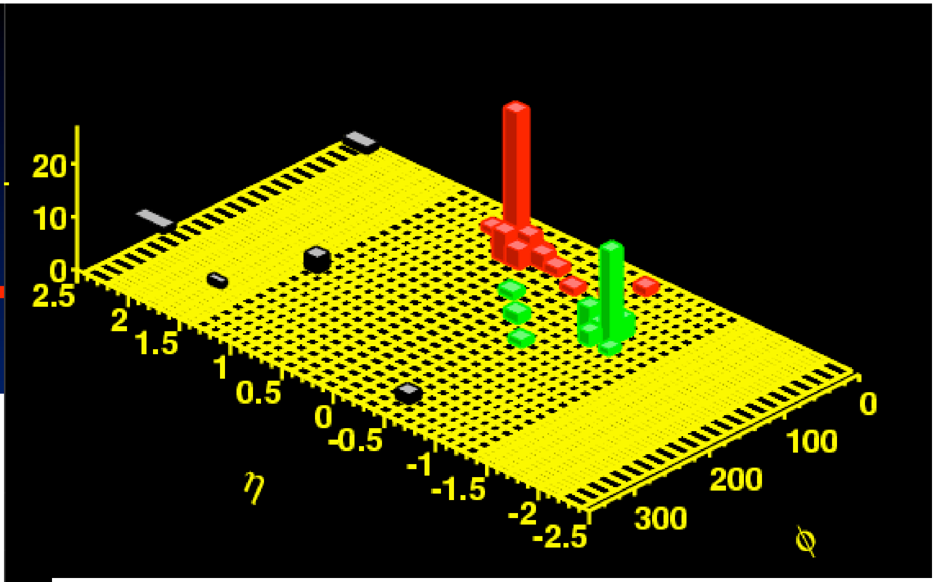
Mass in lepton+jets channel with a b-tagged jet

$$177.5^{+12.7}_{-9.4}\,(\mathrm{stat}) \pm 7.1(\mathrm{syst}) \quad \mathrm{GeV}/c^2$$

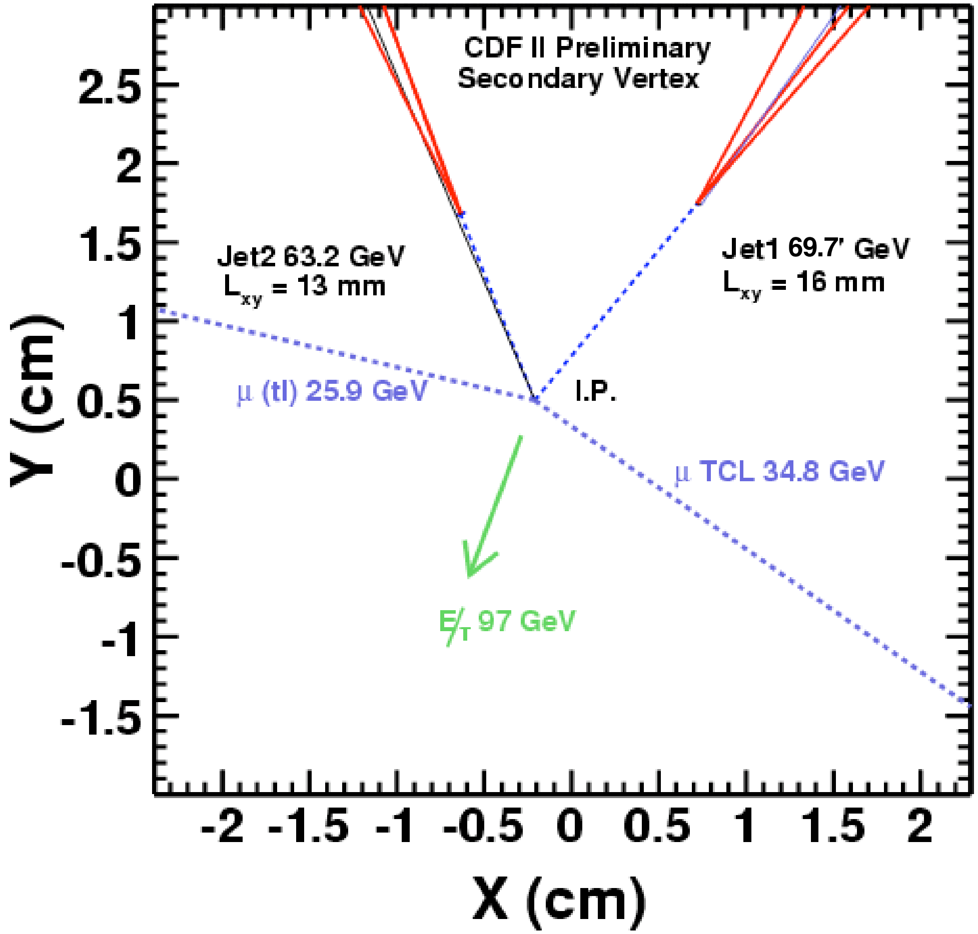
Mass in dilepton channel

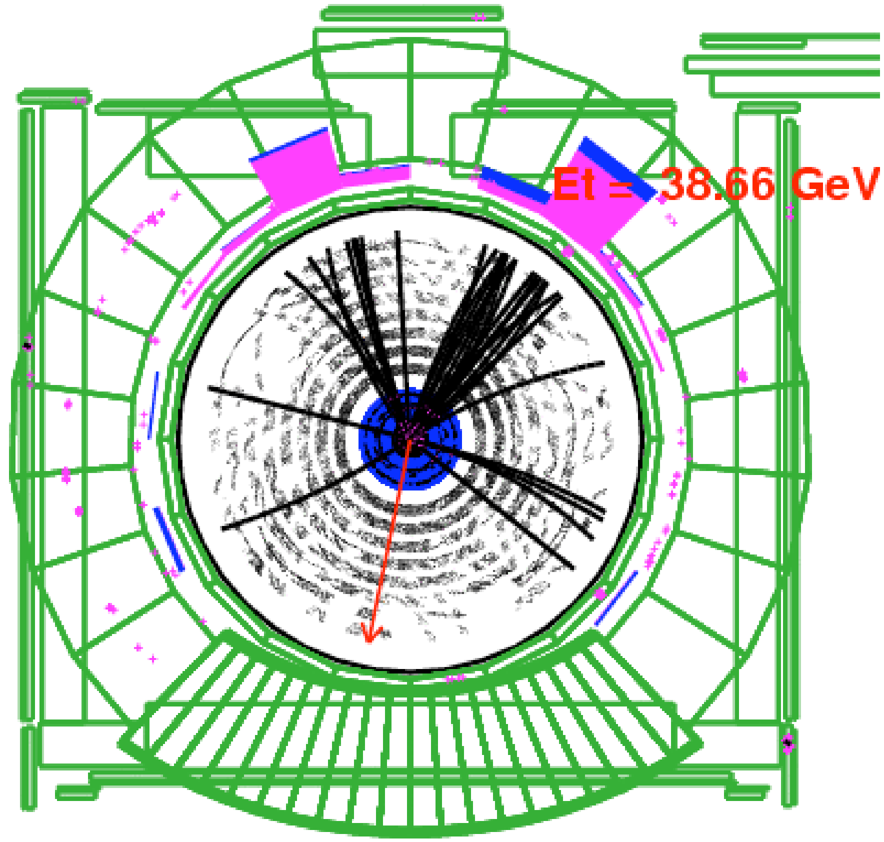
$$175.0^{+17.4}_{-16.9}\,(\mathrm{stat}) \pm 7.9(\mathrm{syst})\ \mathrm{GeV}/c^2$$

Double b-tagged di-lepton event



Run 162820 Event 7050764 Sun May 11 16:53:57 2003





What can we do with 2 fb^{-1} ?

- Will have 20 times larger dataset than now and improved acceptance:
  - statistical error about 0.5-1 GeV
  - maybe better with fancier statistical techniques
- Goal for 2 fb^{-1} (TDR): 3 GeV but less would be better
- Present systematic error: 7 GeV

Systematic Error needs to be reduced by nearly factor of three!

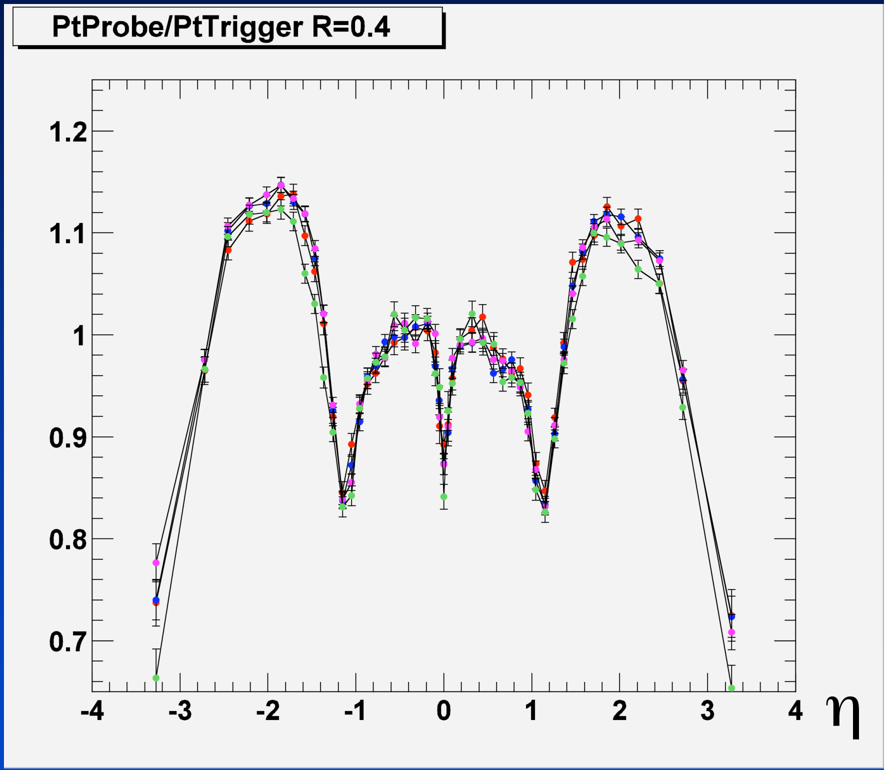
Systematic Uncertainties

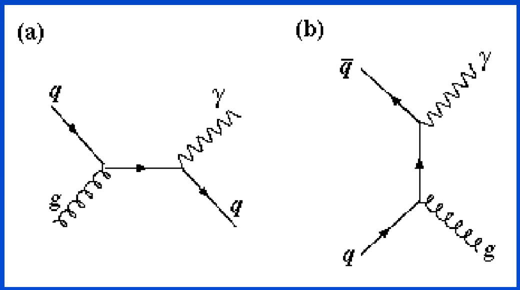
Source	Error (GeV)
Jet Energy Scale	6.2
Initial-State-Radiation	1.3
Final -State-Radiation	2.2
Monte Carlo Generators	0.5
Parton Distribution Functions	2
Other MC modeling (e.g. Pt of ttbar)	1
Background Shape	0.5
B-tagging	0.1
Total syst. Error	7.1

- Jet Energy Scale by far the largest
- ISR and FSR reducible but hard to estimate "true" error
- PDF probably over-estimated

How do we Calibrate?

- Use di-jet events to calibrate forward to central: depends on
  - detector simulation of cracks and plug cal. Response
  - Statistics
- Tune simulation to describe single particle response of calorimeter against well calibrated tracks (isolated tracks in situ + test beam): calorimeter E/ track p
- Use prompt photon events to ultimately check the jet energy scale:
  - not used for calibration
  - only used to set the syst. error





Systematic Uncertainty due to Jet Energy Scale

Source	Error (GeV)
Relative (Plug to Central)	2.9
Central Calorimeter Calibration	5.3
Correction to Hadron Scale	2.4
Correction to Parton Scale ("out of 0.4 cone")	1.8

Purely exp.:

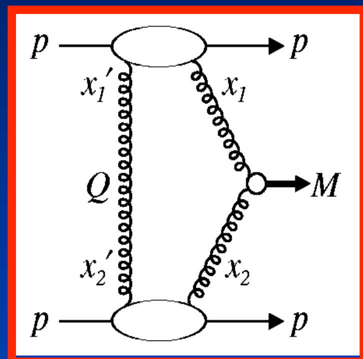
Will achieve 3 GeV "rather soon"

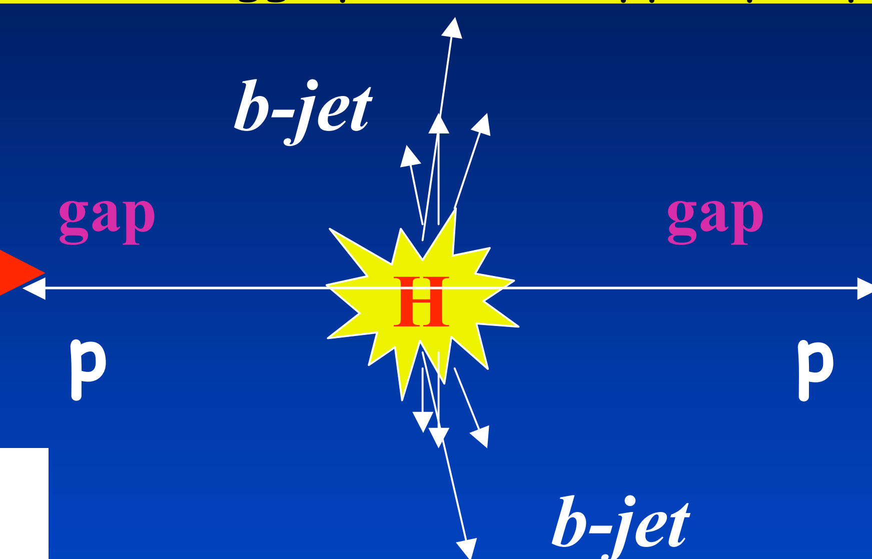
Largely MC modelling: fragmentation and QCD radiation

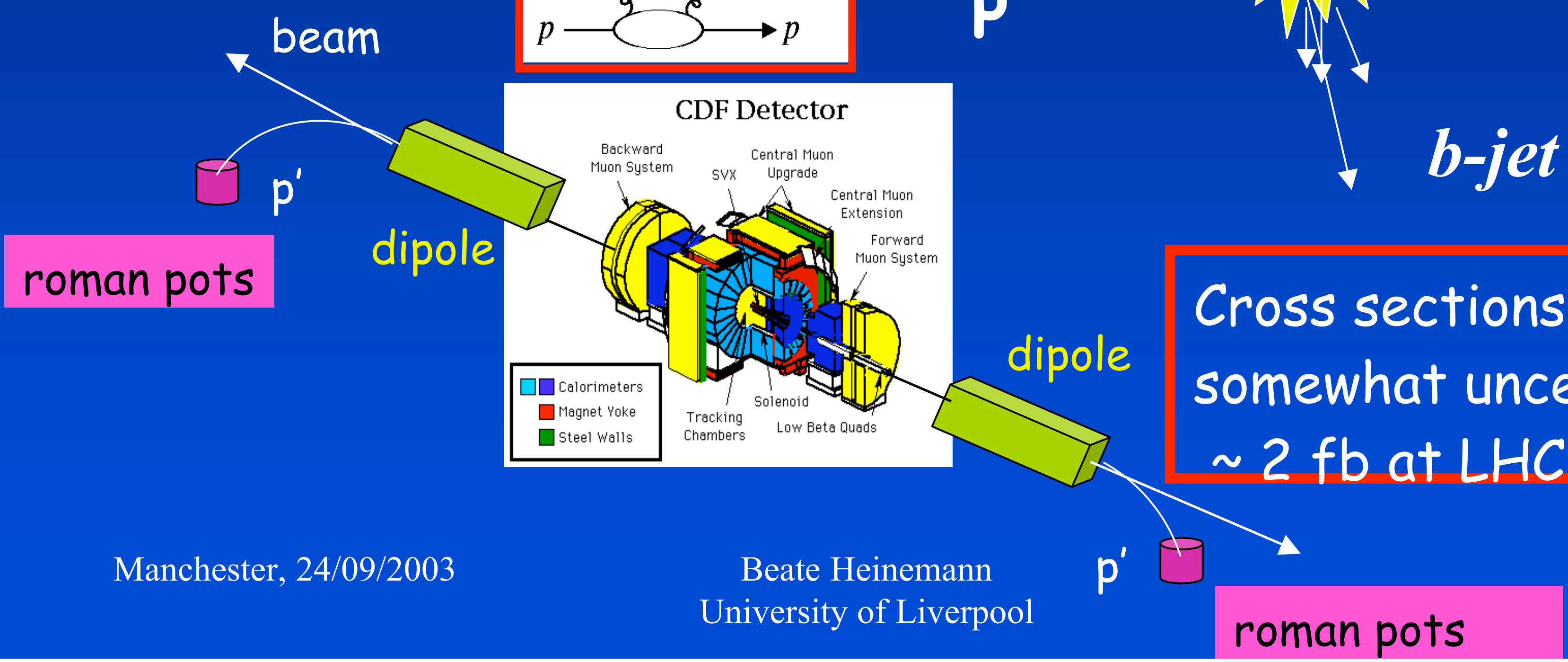
=>Rely on phenomenlogy

Exclusive Higgs

A recent development: search for exclusive Higgs production pp→ p H p

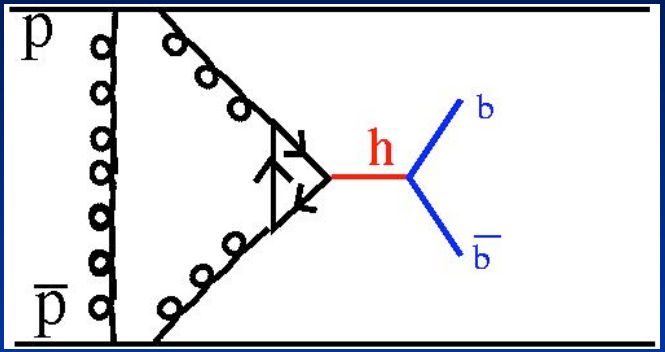






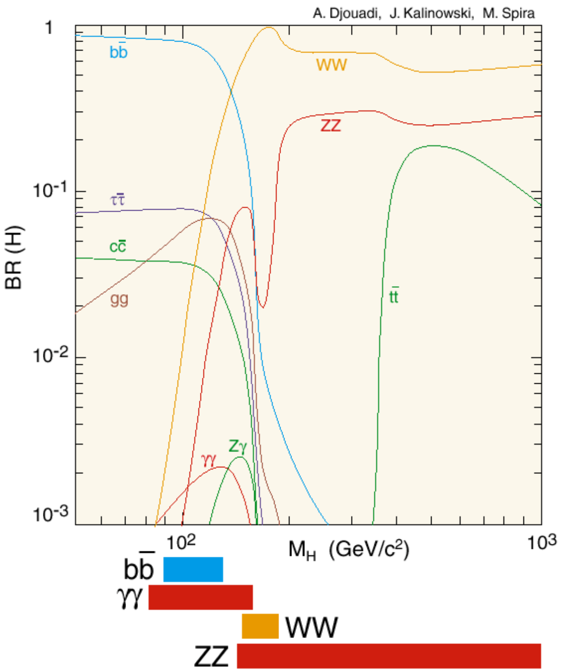
Cross sections somewhat uncertain
~ 2 fb at LHC

Exclusive Higgs Production



Measure _ in

Roman Pots



Reconstruct mass from protons only:

$$M_h = \sqrt{(p_1 - p_1' + p_2 - p_2')^2} \approx \sqrt{\xi_1 \xi_2 s}$$

Mass resolution of O(1 GeV/c^2) independent of decay mode

Access all decay modes=> measure coupling to mass!

Put RP's into ATLAS? Workshop in Manchester in December (B. Cox)

Exclusive Higgs: Competitive channel at LHC?

30 fb^{-1} at LHC

Higgs signal		number of events: signal	number of events: background	S/B	significance $S/\sqrt{S+B}$
a) $H \to \gamma\gamma$	CMS	313	5007	$0.06 \left(\frac{1\ \mathrm{GeV}}{\Delta M_{\gamma\gamma}}\right)$	4.3σ
	ATLAS	385	11820	$0.03 \left(\frac{2\ \mathrm{GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$, $H \to b\bar{b}$		26	31	$0.8 \left(\frac{10\ \mathrm{GeV}}{\Delta M_{b\bar{b}}}\right)$	3σ
c) $gg^{PP} \to p + H + p$, $H \to b\bar{b}$		11	4	$3 \left(\frac{1\ \mathrm{GeV}}{\Delta M_{\mathrm{missing}}}\right)$	3σ

DeRoeck, Khoze, Martin, Orava, Ryskin **Eur.Phys.J.C25:391-403,2002**

Exclusive Higgs: Status of Theory

(fb)	M_H=120 GeV:	Tevatron	LHC	Normalisation
Cudell, Hernandez (1994)				
	exclusive	30	200-400	elastic and soft pp
ox, Forshaw, Heinemann: Phys.Lett.B540:263-268,2002				
	nelastic	0.03-0.1	2-4	HERA x gap survival
hoze, Martin, Ryskin: Eur.Phys.J. C23 (2002) 311-327				
	nelastic	~0.05	~3	

- Predictions difficult due to soft gluon contributions

-Two predictions agree but need experimental testing!

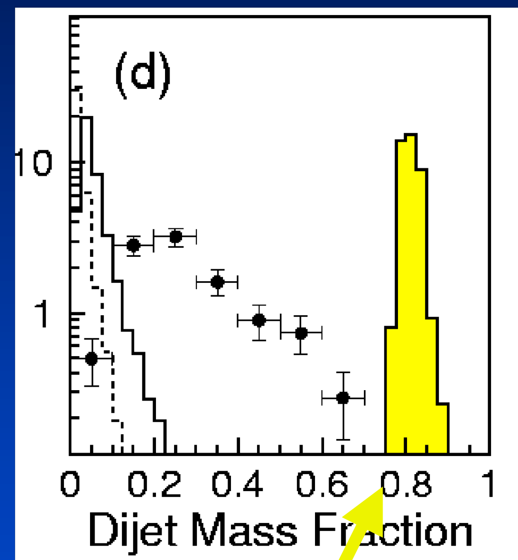
Exclusive Higgs: Experimental Status I

Up to one year ago: All predictions tested by just one run I measurement of DPE dijet-production (2 jets Et>7 GeV):

_(inel.)=44±20 nb

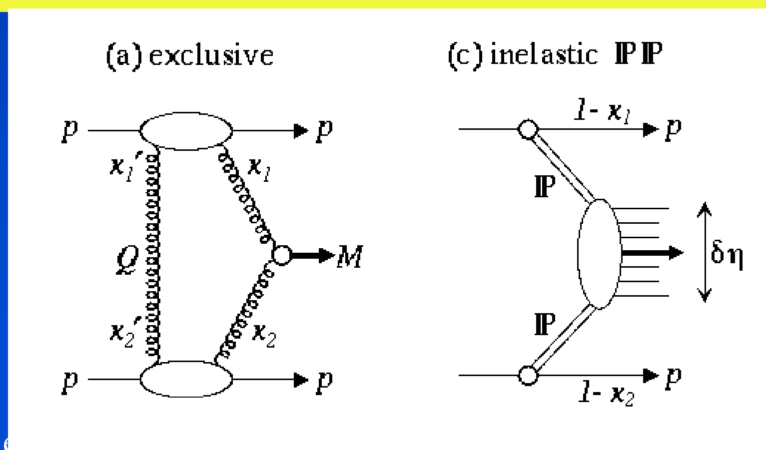
_(excl.)<3.7 nb at 95% C.L.

CDF Run I data



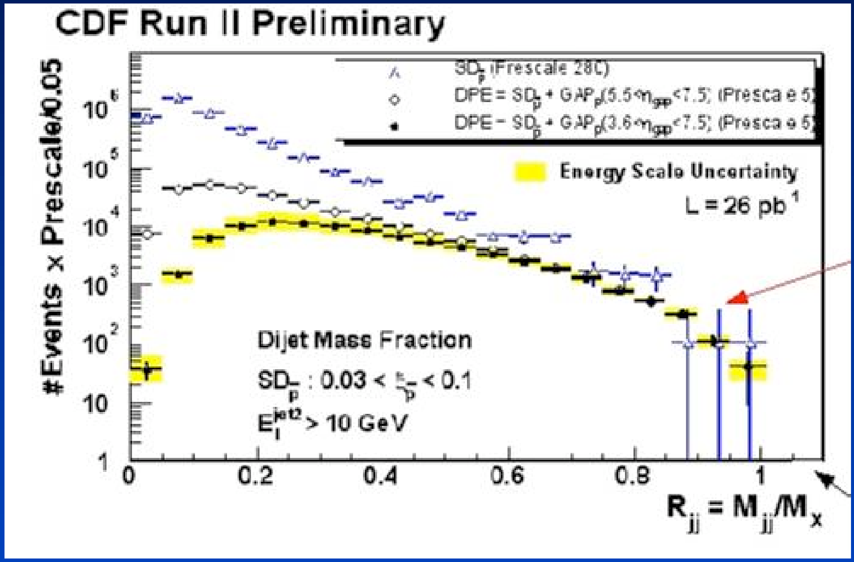
M(j,j)/M(all)

Experimentally a bit less than 1 due to finite jet size



Exclusive Higgs: Experimental Status II

- Run II DPE:
  - Lower prescale due to ability to trigger on gaps and RP tag
  - Better gap detection due to new MiniPlug (3.5-5.5)



CDF Run II data

No "exclusive peak" seen:cross section for

R_{jj}>0.8, $|\eta_{jet}|$<2.5, 0.03<_<0.1, $3.6<\eta_{gap}<7.5$:

Jet Et>10(25) GeV: _=970±65 (34.2±4.7) pb

Upper limit on exclusive cross-section

Exclusive Higgs:

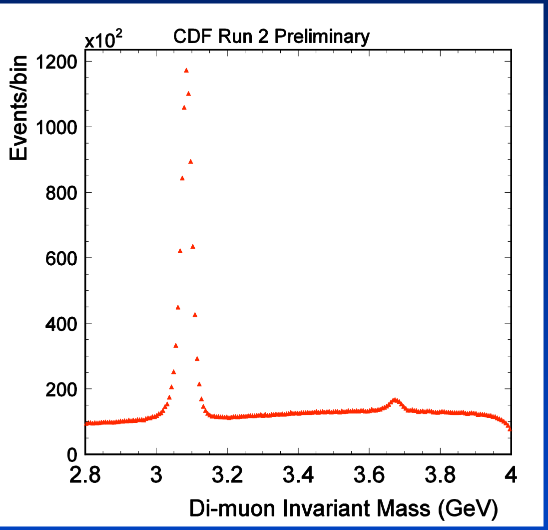
Measurement of χ_c Production

KMR predict sizable cross-section for exclusive χ_c (0++ state):

$\sigma(\chi_c) \approx 600$ nb

BR(χ_c _ J/_+_): 1%

BR(J/__μμ): 6%

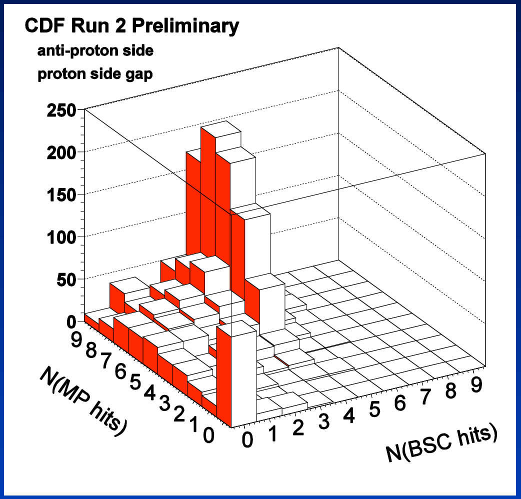


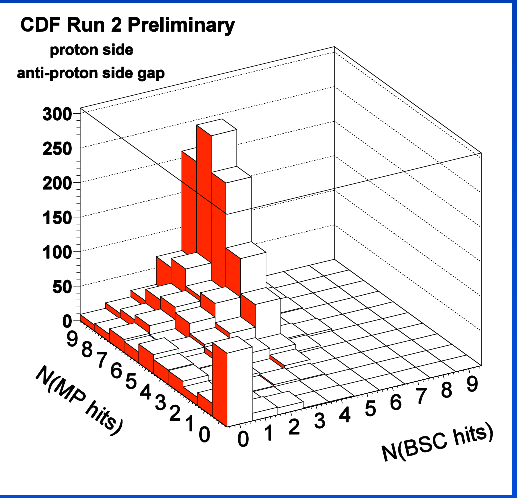
Strategy:

- trigger on J/Psi muons (Pt>1.5 GeV, η<0.6)
- Ask for rapidity gaps (7.5>|η|>0.6)
- Look for low Et photon (about 300 MeV!)

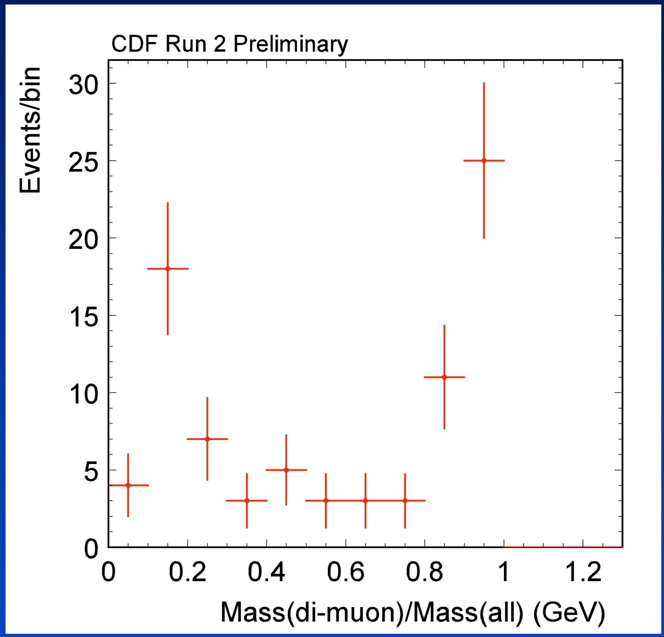
Exclusive J/Ψ and χ_c

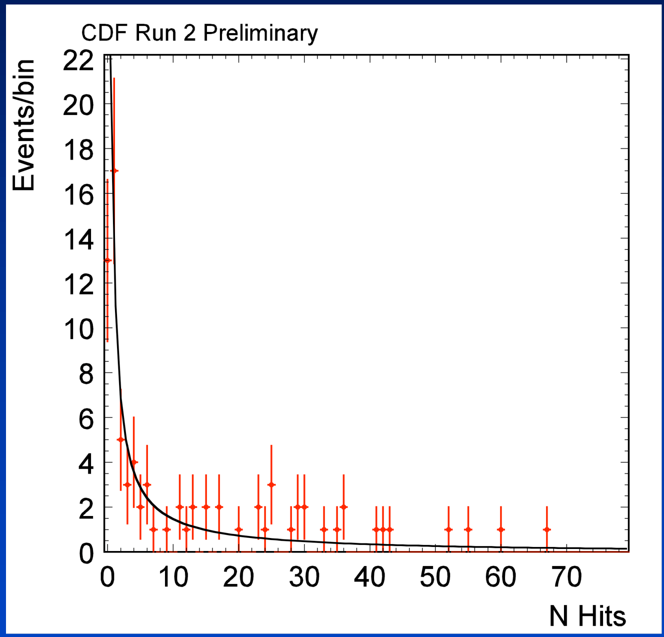
- "MiniPlug" and Beam-Shower-Counters cover $3.5<\eta<5.5$ and $5.5<\eta<7.5$:
  - Observe about 100 J/Ψ events with rapidity gap on both sides
- Central Detector:
  - Demand at maximum one em tower above 100 MeV in central (from chic decay)
  - Apply cosmic filter
- => 23 events (10 with photon candidate)





How “exclusive” are the events?

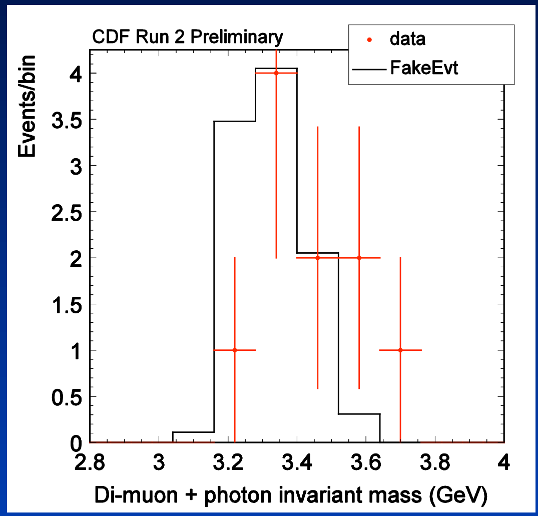


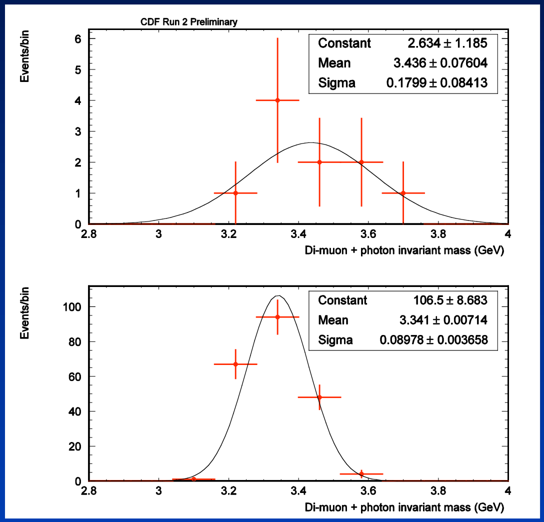


-Don’t know: therefore quote upper limit

-Need higher statistics

Exclusive J/Ψ and χ_c





Events compared to χ_c^{0++} MC:

- consistent but may have contributions from e.g. χ_c^{2++}

- and/or non-exclusive events

Upper limit on x-section: _<48±18(stat.)±39(syst.) pb

KMR for η<0.6: _≈30-140 pb not ruled out (yet)

Conclusion and Outlook

- Physics at the TeVatron is back:
  - Have twice the Run I luminosity
  - Have phantastic detector
  - Analyses not as mature as Run I yet but getting there…
- Hoping for high luminosity in next few years:
  - Observe RAZ for first time?
  - Measure top mass to <3 GeV precision?
  - Understand exclusive production at hadron colliders

Tevatron operating parameters

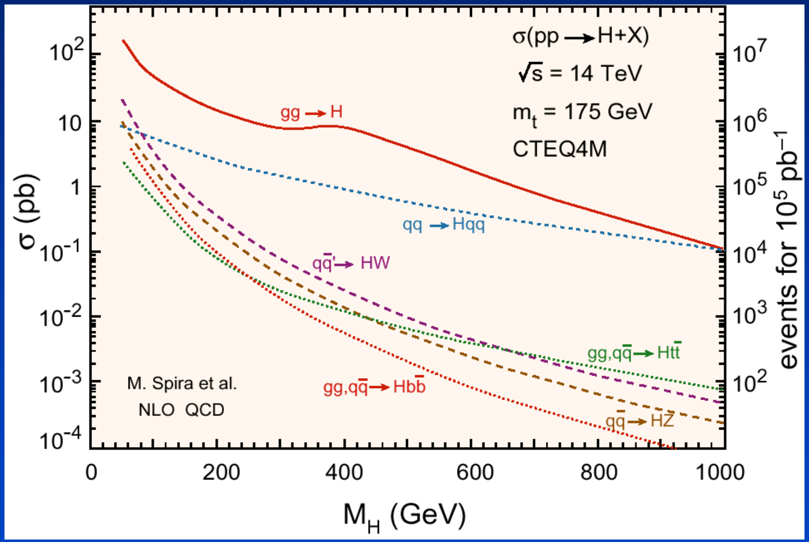
	Run 1	Run 2	Now
Date	1992 – 1996	2001 - 2009	2003
Integrated Luminosity	110 pb^{-1}	4 – 9 fb^{-1}	250 pb^{-1}
c.m. energy	1.8 TeV	1.96 TeV	1.96 TeV
Luminosity	2×10^{31} cm^{-2} s^{-1}	2×10^{32} cm^{-1} s^{-1}	5×10^{31} cm^{-2} s^{-1}
Bunch spacing	3.5 μs	396 ns	396 ns

Beyond the TeVatron: LHC

- pp-collider at CERN
- Center-of-mass energy:
  14 TeV
- Starts operation in 2008
- 3 years “low” luminosity:
  10 fb^{-1} /yr
- High luminosity:
  100 fb^{-1} /yr

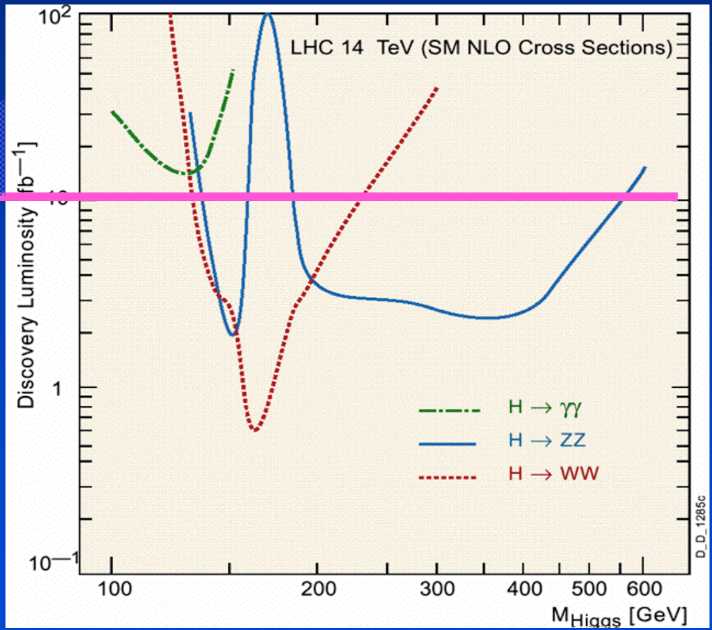
Di-Boson Production via Higgs-decay @ LHC

Dominant Production: gg-> H



Decay: Di-bosons
(__, WW or ZZ)

one year



Main Higgs discovery channels at LHC:

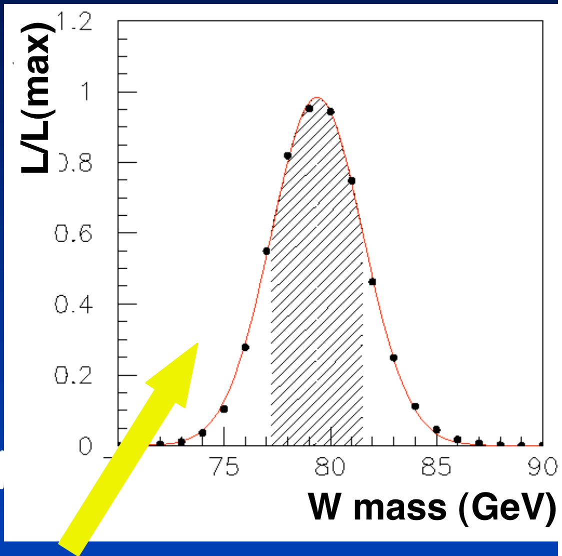
two bosons in final state

Run 2 Top Expectations

	Run 1	Run 2	
Date	1992 - 1996	2001 - 2007	
Int Luminosity	110 pb^{-1}	2000 pb^{-1} -> 15000 pb^{-1}	
#top produced	550	15000+	
		Run 2a	Run 2b
Mass Precision	2.9%	1.2%	1.0%
σ(tt) Precision	25%	10%	5%

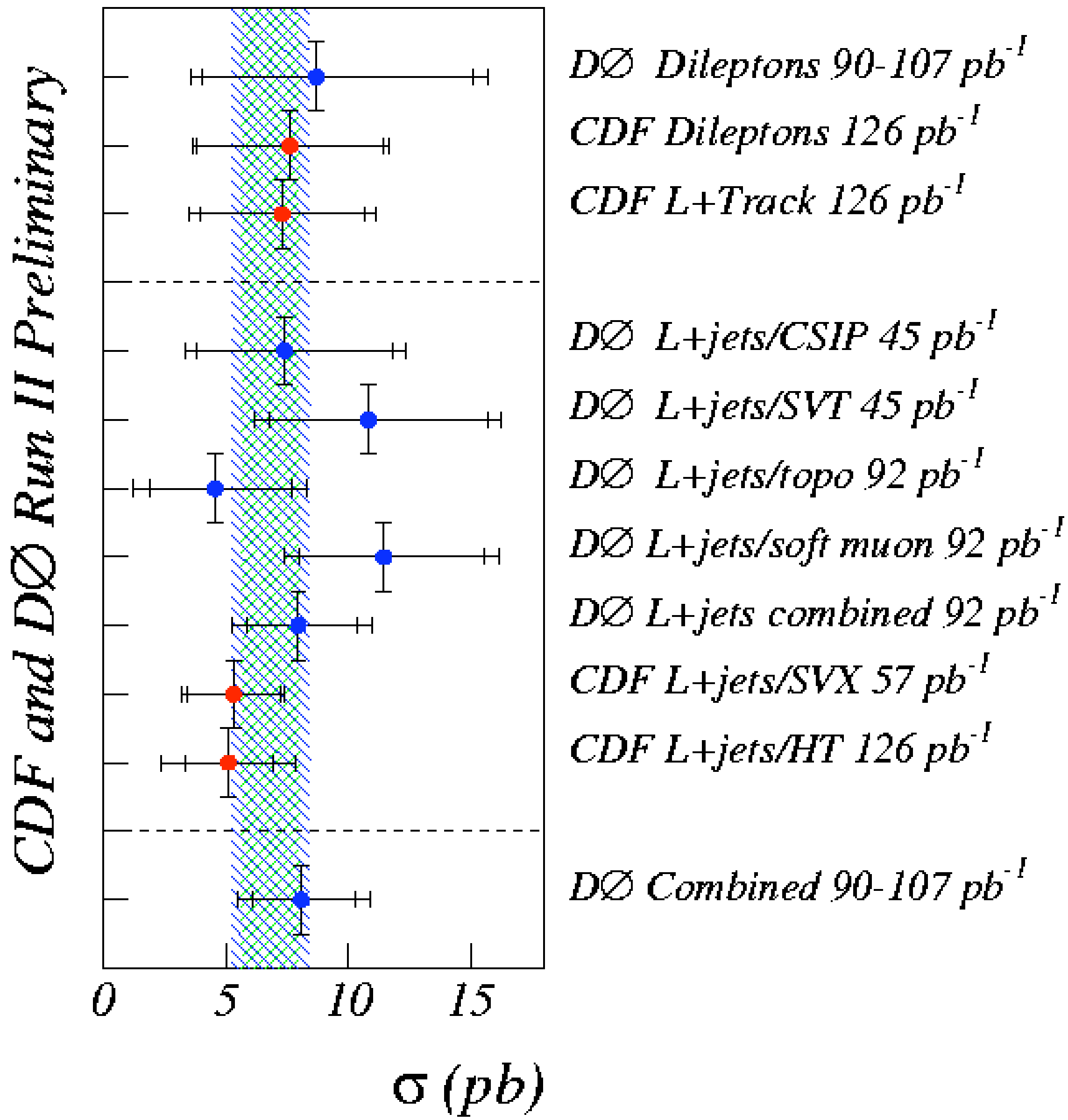
Handles for a precision measurement

A precise measurement of the top mass combines cutting edge theoretical knowledge with state of the art detector calibration



- Jet energy scale
  - gamma-jet balancing: basic in situ calibration tool
  - Z+jet balancing: interesting with large statistics
  - Hadronic W mass: calibration tool in tt double tagged events
  - Z→bb mass: calibration line for b-jets, dedicated trigger
- Theory/MC Generators: understand ISR/FSR, PDF's
- Simulation: accurate detector modeling
- Fit methodology: how to optimally use event information
- Event selection: large statistic will allow to pick best measured events

Run II cross section summary



$8.7^{+6.4}_{-4.7}(\text{stat})^{+2.7}_{-2.0}(\text{syst}) \pm 0.9(\text{lum})$

$7.6^{+3.8}_{-3.1}(\text{stat})^{+1.5}_{-1.9}(\text{syst})$

$7.3 \pm 3.4(\text{stat}) \pm 1.7(\text{syst})$

$7.4^{+4.4}_{-3.6}(\text{stat})^{+2.1}_{-1.8}(\text{syst}) \pm 0.7(\text{lum})$

$10.8^{+4.9}_{-4.0}(\text{stat})^{+2.1}_{-2.0}(\text{syst}) \pm 1.1(\text{lum})$

$4.6^{+3.1}_{-2.7}(\text{stat})^{+2.1}_{-2.0}(\text{syst}) \pm 0.5(\text{lum})$

$11.4^{+4.1}_{-3.5}(\text{stat})^{+2.0}_{-1.8}(\text{syst}) \pm 1.1(\text{lum})$

$8.0^{+2.4}_{-2.1}(\text{stat})^{+1.7}_{-1.5}(\text{syst}) \pm 0.8(\text{lum})$

$5.3 \pm 1.9(\text{stat}) \pm 0.9(\text{syst})$

$5.1 \pm 1.8(\text{stat}) \pm 2.1(\text{syst})$

$8.1^{+2.2}_{-2.0}(\text{stat})^{+1.6}_{-1.4}(\text{syst}) \pm 0.8(\text{lum})$